The structure and properties of puffed rice cakes

A thesis submitted in fulfillment of the requirements for the degree of Doctor of Philosophy

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Declaration

I certify that except where due acknowledgement has been made, the work is that of the author alone; the work has not been submitted previously, in whole or in part, to qualify for any other academic award; the content of the thesis is the result of work which has been carried out since the official commencement date of the approved research program; and, any extra work, paid or unpaid, carried out by a third party is acknowledged.

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Publications and presentations

Parts of the research reported in this thesis have been published and the details are as follows:

Conference presentations

One paper was presented at Chemeca 2007, Academia and Industry Strengthening the Profession held in Melbourne, Victoria 23rd – 26th September 2007. The details of the paper are:

Sharma, J., Jollands, M.C., Allan, M., Small, D.M. and Rolfe, S. (2007) A DSC Study of Gelatinisation of Rice, In: Rhodes, M (Ed), Academia and Industry Strengthening the Profession – Proceedings of the Chemeca Conference 'Chemeca 2007, Academia and Industry Strengthening the Profession'. Held from the 23rd - 26th September 2007, Melbourne, Australia and published by Engineers Australia, Barton, ACT, ISBN 0 858 25844 7.

Papers were also presented at the 58th and 59th Australian Cereal Chemistry Conferences held in Gold Coast, Queensland 31st August to 4th September 2008 and Wagga Wagga, New South Wales 27th – 30th September 2009. The details of the papers are:

Sharma, J.K., Jollands, M.C., Small, D.M. and Doig, S. (2008) The thermal properties of starch extracted from Amaroo rice, published in: Panozzo, J.F. and Black, C.K. (Eds), *Cereals 2008 – Proceedings of the 58th Australian Cereal Chemistry Conference*, held from 31st August-4th September 2008, Surfers Paradise, Gold Coast, Queensland, Australia and published by the AACC DownUnder Section, North Ryde, NSW. pp 87-90, ISBN 1 876892 18 1.

Sharma, J.K., Jollands, M.C., Small, D.M. and Rolfe, S. (2010) Study of the microstructure and mechanical properties of puffed rice cakes, published in: Blanchard, C., Pleming, D. and Taylor, H. (Eds), *Cereals 2009 – Proceedings of the 59th Australian Cereal Chemistry Conference*, held from 27th -30th September 2009, Wagga Wagga, New South Wales, Australia, and published by the AACC DownUnder Section, North Ryde, NSW. pp 77-83, 1 876892 37 4.

Abstract

Puffed cereal grains are commonly used as ingredients in a variety of food products, provide characteristics including crispiness which appeal to consumers. In addition to the traditional puffed breakfast cereals, newer developments have included health bars, confectionery and savoury foods. Among the most popular of these are rice cakes, typically manufactured from brown rice. There are relatively few previous scientific studies which have focused on rice cakes, the optimal conditions for their processing or upon the puffing of rice. In addition, past publications have not discussed the mechanism of puffing or the adhesion of rice grains during processing, the roles of proteins, bran, lipids or the ageing of rice. There is virtually no information on the microstructure of puffed rice cakes or related products.

In the context of current practical problems regarding the quality of the finished products, particularly the relatively high rates of breakage, the objectives of this study have been to examine the quality of rice cakes prepared using different processing variables and to investigate the mechanism of puffing and adhesion involved. A further feature included in this study has been the measurement of cell size in order to provide a basis for understanding the mechanism of adhesion in the puffed rice cakes.

A series of trials were run in which rice cakes were made with different levels of tempering moisture (16, 18 and 20%), heating temperature (248, 258 and 268°C), processing time (2, 4 and 6 sec) and the cycle time (5.8, 6.0 and 7.0 seconds). In addition, selected types of rice (brown and white, waxy, low and high protein samples) have been evaluated along with the incorporation of either oil or sugar in the formulation. The physical properties of the resultant rice cakes were measured and it was found that the volume increased with increasing heating temperature and cooking time for brown rice samples at each of the tempering moisture levels evaluated. Similar results were found for white rice and when either oil or sugar was added to the formulation, whereas for cakes made with waxy rice, volume did not change. Textural attributes of the products were measured by a compressive analysis and data expressed in terms of stiffness. Relatively little variation was observed in this parameter except for cakes made with oil where the stiffness values were relatively low. Shorter cycle times during production were found to increase the volume and stiffness characteristics of the cakes.

The scanning electron microscope was used to produce images showing the internal microstructure of rice cakes and from these cells size measurements were made. For all treatments the cell size distribution was relatively heterogeneous regardless of the processing variables applied or the type of rice. The heterogeneity appears to reflect a number of contributing factors including the endosperm structure of the rice as well as the presence of chalkiness. Flaps of bran were observed along with densely packed small cells adjacent to grain boundaries in cakes prepared with brown rice. Differences were noted in the appearance of images depending on the way in which the samples were fractured indicating that different mechanisms applied for strong and weak cakes: in the former the crack develops through the grains, whereas in weak cakes the crack appears to form between the grains.

During rice cake processing, puffing of rice grains occurs upon rapid heating in a hot mould. Unbound water vapourises and the steam nucleates gas cells within the matrix of starchy liquid. The gas diffuses into the cells, which expand while the temperature decreases rapidly due to the energy absorbed as the latent heat of vaporisation. The puffed foam structure solidifies on cooling. Another concurrent series of changes involve adhesion and this commences when the rice grains are crushed when the heating chamber is closed. This cracking of the grain and the enclosing bran layers allows more rapid diffusion of steam from the rice grains during puffing and expansion, and facilitates transfer of starch molecules to the rice grain surface. Rice grains expand until they are fused with neighbouring grains and expansion continues until all of the available space in the mould is occupied. The rice starch molecules diffuse and become entangled while the temperature is high and then, upon cooling, a rigid structure forms between the grains. There are two main factors contributing to the overall adhesion of the cake and hence product stiffness: the mechanical strength of adhesion between the surfaces of adjacent puffed rice grains and that of individual grains. The break strength of the cake is determined by whichever of these two is the weaker.

In conclusion, the physical characteristics of rice cakes do not alter significantly with different processing variables. Oil affects the integrity of the rice cakes. The heterogeneity of cell size in rice cakes shows how cells nucleate and heat plays an important part during puffing. Higher processing temperatures appear to accelerate puffing. The present study contributes to an enhanced understanding of the effects of processing and compositional variables on the mechanisms of puffing and adhesion. Further research is recommended particularly to further explore the importance of processing variables including cycle time and to extend the preliminary studies of composition variables reported in this thesis. The potential of other ingredients that might enhance the adhesion of rice cakes while allowing optimal puffing to occur also warrants consideration as efforts continue towards an increased understanding of rice cake quality.

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Abbreviations

% DS	dry substance
°C	unit of measurement for temperature
a*	redness
AACC	American Association of Cereal Chemists
Am	amylose
Ap	amylopectin
b*	yellowness
BR	brown rice
cm^3	SI unit for measuring volume
dmb	dry matter basis
DSC	differential scanning calorimetry
ESEM	environmental scanning electron microscopy
kPa	SI unit for measuring pressure (kiloPascal)
L*	lightness value
mg	milligram
mm	millimetre
n	the number of replicate analyses used in calculation of individual results
N	SI unit for measuring force
sd	standard deviation
sec	SI unit for measuring time
Tg	gelatinization temperature
WR	white rice
X-ray	electro-magnetic radiations

Explanatory notes

The purpose of these notes is to briefly describe the approaches adopted during the preparation of this thesis. They relate to the use of abbreviations, spelling, units of measurement, the expression of analytical results, as well as the referencing of literature sources:

1. Selected abbreviations have been used and these are listed on page xxii of this thesis;
2. Where alternative spellings are in common use then the British rather than the American approach has been adopted in the text. Examples include the term colour (rather than color), and some technical terms;
3. Generally, for the presentation of results SI units have been used;
4. Experimental data is presented on a fresh weight (or wet matter) basis rather than a dry weight (or as is) basis unless otherwise clearly specified;
5. In the assessment of the significance of experimental data, standard deviation values have been calculated. These have been used to determine whether mean values are different at the 5% level significance. In selected cases standard deviations have been plotted on graphs as error bars;
6. Throughout this thesis the terms cell and cells have been used to refer to the open, gas filled spaces within the structure of rice cakes, rather than with respect to the plant cells within the original grains; and
7. In the citation and listing of references and information sources, the current recommendations of the Institute of Food Technologists (IFT) for the Journal of Food Science (IFT 2011) have been applied throughout.

Chapter 1

Introduction

The purpose of this chapter is to provide a very brief overview of the research program described in this thesis on the structure and physical characteristics of rice cakes manufactured from brown and white rice grains by a puffing process. The project has been developed on the basis of a thorough review of existing knowledge and, in particular the following issues:

- Cereal grains represent a major staple food source for a large proportion of the world's population. These grains are processed into a wide diversity of food products which provide various nutritional benefits and contribute to wellbeing for consumers;

- Industrially ready-to-eat puffed products are made from wheat, maize (corn), rice and various combinations of cereals and these foods are popular in Australia and many other countries;

- Although utilised extensively on a commercial scale, puffing of grains presents challenges and there are still major concerns regarding the quality of various puffed products made from the cereal grains;

- Rice is a major global crop and food source, especially in tropical and subtropical regions and this is increasingly popular for making breakfast cereals, snack bars and rice cakes and also as a light food when puffed as either brown or milled rice by processing at high temperatures;

- There have been a very limited number of scientific reports published on the influence of processing variables on the manufacture of rice cakes. Up until now, the primary focus has been upon the use of different types of rice materials, particularly comparing the application of long and short grained rices;

- In addition, there is little data available on the textural and micro- structural properties of rice cakes, as well as the use of other ingredients including sucrose, salt, shortening and wheat starch;

- Even less is known on puffing and the adhesion of rice grains during the manufacture of rice cakes, although it thought that the mechanism of puffing and adhesion is crucial to the quality of the resultant rice cakes and their ability to withstand the various stages from raw materials to final production, packaging, transportation and subsequent merchandising;

- Relatively little information has been published on puffing of rice and it is possible that the more extensive knowledge gained from the processing of synthetic polymers maybe relevant. The techniques for puffing of rice appear to be similar to those used in preparation of synthetic foams. The latter are first saturated with a blowing agent and are then subjected to heating and a reduction in pressure, causing the blowing agent to vaporise, resulting in puffing. It may therefore be useful to apply the knowledge of polystyrene foams and procedures applied in their characterisation, to the process of rice puffing;

Accordingly, this thesis reports on an investigation designed to fill the gap in our understanding of the puffing of rice and the processing of rice cakes. This is based on the hypothesis that an understanding of the changes occurring during puffing and the optimisation of process variables can be useful for reducing breakage during manufacture of rice cakes. The puffing and adhesion of rice grains during rice cake production have been evaluated along with the physical properties of the puffed rice, particularly that of product structure.

Chapter 2

Background and literature review: an overview of rice

The purpose of this chapter is to provide background on the structure, composition and utilisation of rice. The emphasis is upon those aspects of rice quality relevant to its use in the processing of puffed products and includes brief descriptions of rice varieties, grading, storage, morphology and chemical composition.

2.1 Introduction

Cereal grains are widely processed for ready-to-eat-breakfast cereals, snack food as well as puffed grain cakes. These products do not require further cooking by the purchaser and can provide nutritional advantages with some being high in fibre, low in fat and offering the benefits associated with whole grain products. The cereal grains which are most widely used are wheat, rice, corn, oats, and barley.

2.2 Types of cereal grains used for puffed products

Of the cereal grains, corn has been utilised for many years and is continues to be widely used for making the popular breakfast cereal cornflakes and the puffed snack popcorn. Corn is followed closely by wheat which is commonly incorporated during production of breakfast cereals, puffed wheat snacks and wheat cakes. Whilst rice has been consumed as a staple food and in various forms for centuries it has gained considerable importance in recent years being processed, both alone and in combination with other cereals. Another cereal grain that has also attracted interest in recent times is oats which is typically used in the form of rolled oats and yet another cereal grain, barley, is also considered suitable for processing. Increasingly cereal grain foods are attracting attention and the demand for ready-to-eat food products made from cereal grains continues to expand (Wrigley 2004).

The basic steps in processing of each of the cereals grains into breakfast cereals and puffed food are similar. In recent times processes that have been used for other cereals have been applied to rice which is now used extensively in processing due to the unique flavour and textural properties it provides. Rice is increasingly being converted into flakes, shredded rice, multi-grain cereals as well as puffed products which can be prepared by a number of processing techniques. Puffing of rice can be carried out in hot sand, in hot oil, in an oven and by puffing gun, rice cake machine as well as ultrasound (Caldwell and Kadan 2004). In order to provide background to a study of the influence of processing parameter, the structure and composition of rice will be reviewed briefly.

2.3 Rice and its grain structure

The rice crop which is grown predominantly around the world is the species *Oryza sativa* L. although the Oryza genus includes around 20 species. The rough form of rice which is harvested and is often referred to as paddy rice consists of the edible portion, the rice caryopsis, as well as the husk (Juliano 2004).

A typical mature rice grain has a caryopsis in which the single seed is fused with the wall of the pericarp (ripened ovary) forming a seed-like grain (Figure 2.1). The caryopsis is also commonly referred to as brown rice because of its brownish appearance and in comparison with some of the other cereal grains; the bran layer is relatively thin. In rice, the bran consists of three distinguishable layers, which are the pericarp, tegumen and aleurone layer (Juliano 2004).

Rice endosperm is divided into two regions, the sub aleurone (the two outermost layers of cells located just beneath the aleurone layer) and the central region, consisting of the remainder of the starchy endosperm. The central endosperm region is composed almost entirely of larger, polygonal, compound starch granules (3-9 μm in diameter). These are present in thin-walled parenchyma cells (elongated radially) and the lateral (or flattened) side tends to have polygonal or slightly elongated shaped cells (length to width ratio, 0.7 -1.4), while the dorsal side has more elongated granules (length to width ratio, 0.2-1.0). In contrast, in the peripheral cells of the starchy endosperm the starch granules are small (2-4 μm). These are also fewest in the lateral and ventral peripheral cells, forming tiny clusters well separated by the surrounding dense protein material (Juliano 2004).

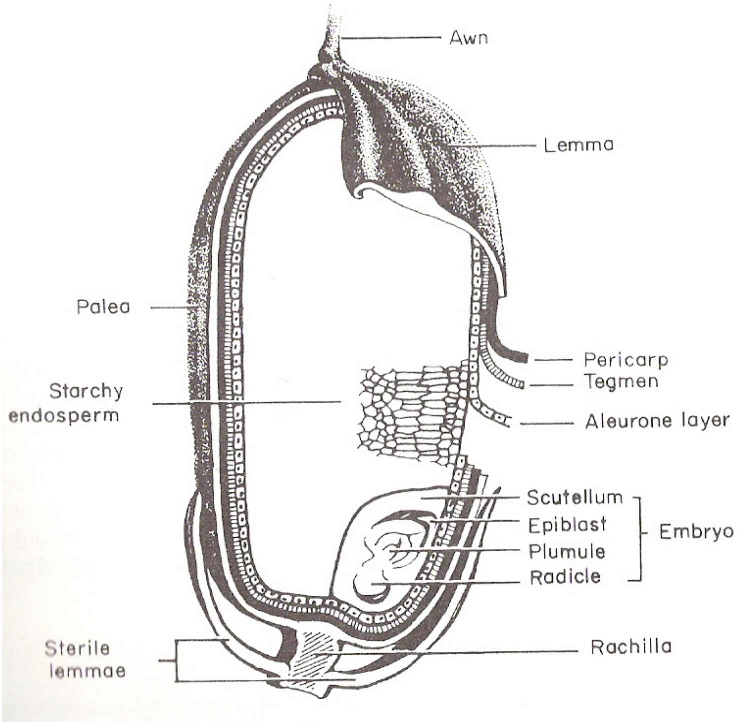


Figure 2.1 Cross-sectional view of a grain of rice showing husk layers and the central areas including the cellular arrangements

Notes Figure sourced from Juliano and Aldama (1937)

Different rice varieties differ in cross-sectional structure of the endosperm tissue and in the hardness of the different areas of the endosperm. One of the conditions found in rice samples is that commonly known as chalkiness. In this case, the endosperm may be "chalky" in appearance in some non-waxy rice varieties. Whereas the endosperm is usually translucent and contains polygonal starch granules packed in a compact arrangement with no inter-granular space that, seen in chalky grain is different. In these, the endosperm is opaque, containing spherical starch granules loosely arranged with intergranular spaces (Juliano 1985, 2004).

The embryo of the rice grain is relatively small and is located on the ventral side at the base of the grain. The embryo is bounded on the outside by a single layer of endosperm cells, the modified aleurone layer, and by the fibrous cellular remains of the pericarp, seed coat and nucleus i.e., the caryopsis coat. The starchy endosperm borders the inner edge of the embryo. Studies on the ultrastructure of rice embryo indicate that parenchyma cells (storage reserves) can be divided into three classes:

1) Those having globoids in protein bodies and scattered lipid bodies throughout the cytoplasm;
2) Cells having protein bodies and peripheral lipid bodies; and
3) Those lacking protein bodies and having peripheral lipids.

Category 1 cells are primarily storage cells as they have a large quantity of proteins, Category 2 cells are primarily epidermal and category 3 cells are pro-vascular cells (Juliano 1985).

The aleurone layer is the outermost layer of endosperm tissues, which completely surrounds the rice grain and the outer side of the embryo and differs in morphology and function from those of the starchy endosperm. There are two types of aleurone cells: one type around the starchy endosperm and the other type around the embryo and the former are cuboidal and have densely packed cytoplasm. The latter type of aleurone cell is called the modified aleurone layer and these cells have a less densely packed cytoplasm, and are rectangular. Within the aleurone cells, there are structures known as aleurone grains and these are also referred to as protein bodies although these differ in characteristics from the protein bodies which are found in endosperm cells and are also a major storage structure of rice grains (Juliano 1985).

The bran layers including the inner layer referred to as "polish" are removed from the endosperm during milling. These layers consist of fragments derived from the pericarp and seed coat together with the greater portion of the aleurone layer, part of the sub - aleurone layer of the starchy endosperm along with the germ which is also removed during milling.

In chemical compositional terms, starch represents a large proportion of the weight of the rice grain, particularly once the husk layers have been removed. The starch also plays a key role during processing of rice and so the characteristics of this component will be reviewed in the following sections.

2.4 Rice starch

Starch occurs widely as an energy reserve in plants and is unique in that it occurs in structures called granules (Figure 2.2). These are relatively dense and the granules from different botanical sources vary in their size and shape (Reddy and others 1989; Tharanathan 1995; Tharanathan and Mahadevamma 2003; Lawton 2004; Liu 2005). In some sources, the age of the starch may determine the differences in the size of the starch granules (French 1984; Shannon and Garwood 1984). The size of granules in plant sources falls within the range of 1 to 100 μm in diameter (Liu 2005). Commercially, starches are obtained from cereal grain seeds, particularly from corn, waxy corn, high-amylose corn, wheat, and various rices as well as from tubers and roots, particularly potato, sweet potato and tapioca. Starches and modified starches are used extensively as ingredients in the formulation and processing of foods, with functions including binding, foam strengthening, gelling, and moisture retention, stabilising, texturizing and thickening.

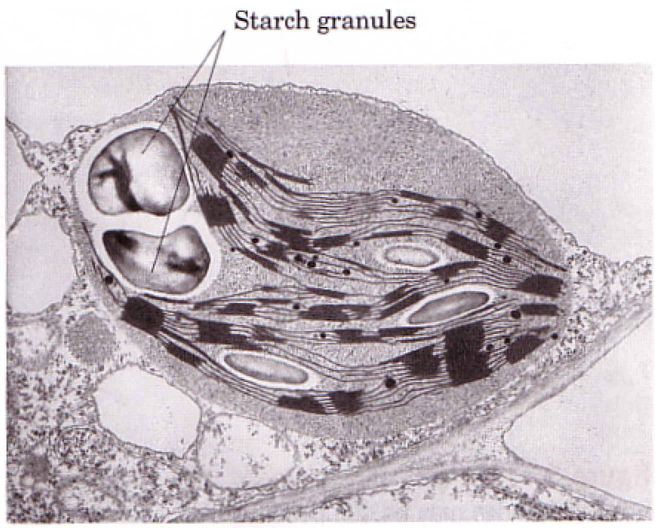


Figure 2.2 Electron micrograph of starch granules in a single chloroplast

Note Sourced from Nelson and Cox (2000)

Starch is the predominant food reserve in rice and white rice contains approximately 90% starch (expressed on a dry matter basis, abbreviated as dmb). It is a natural semi-crystalline polymer that is built from glucose units into either a linear or branched long chain structure and has many exposed hydroxyl groups which attract water through the formation of hydrogen bonding.

Starch in rice is present only in the endosperm cells of mature brown rice, where it exists as compound polyhedral granules which are 3-9 μm in diameter. The rice starch granules cluster within a structure known as an amyloplast and these are spherical to ellipsoidal, varying from 7 to 39 μm in diameter. Each amyloplast contains 20 – 60 small polyhedral granules and is covered by a thin electron-dense matrix which is in contact with protein-like bodies (Houston 1972; Juliano 2004).

The starch crystalline regions are much smaller than the granules and one of the widely applied techniques for studying starch crystals is Differential Scanning Calorimetry (DSC). This approach, used in conjunction with X-ray scattering, has resulted in the identification of three different types of starch crystals and starches are therefore classified as: A-type: characteristic of cereal starches, B-type: found in tuber starches, and C-type: typically found in legumes (Houston 1975; Juliano 2004).

Starch is unique among carbohydrates because it occurs naturally as discrete particles. Starch granules are relatively dense and insoluble and hydrate only slightly in cold water. They can be dispersed in water producing low viscosity slurries that can be easily mixed and pumped, even at concentrations of greater than 35%. A second uniqueness is that most starch granules are composed of a mixture of two polymers: an essentially linear polysaccharide amylose (Am) and a highly branched form amylopectin (Ap). Starches from particular sources have a characteristic ratio of these two polymers. A comparison of the typical properties of rice starch with those of other sources is presented in Table 2.1.

2.5 Components of rice starch: Am and Ap

Almost invariably starch granules are made up of both component polymers, Am (Figure 2.3) and Ap (Figure 2.4) and the molecules are arranged radially within the granules. These contain regions which are crystalline as well as others where the arrangement is non-crystalline and the overall arrangement is one of alternating layers. The clustered branches of Ap occur as packed double helices and these form the crystalline areas which are the more dense layers of starch granules. The other layers which are less dense are described as having an amorphous structure. Am molecules occur intermingled among the Ap molecules and some of these may diffuse from partially water-swollen granules. Particular genetic varieties of rice will have a characteristic ratio of the two molecular forms of starch. The variety Amaroo, which has been used in the research described in this thesis, contains 17 to 19% Am so this is classed as a low Am rice.

Table 2.1 General properties of starches from rice and selected other sources

Description	*Rice starch*	*Waxy maize starch*	*High-Am corn starch*	*Common corn starch*	*Wheat starch*	*Potato starch*	*Tapioca starch*
Granule size (major axis, µm)	2-10	2-30	2-24	2-30	2-55	5-100	4-35
Am (%)	14-25	<2	50-70	28	28	21	17
Gelatinization temp (°C)[a]	54-76	63-72	66-170b	62-80	52-85	58-65	52-65
Relative viscosity		medium-high	very low[b]	medium	low	very high	high
Paste rheology [c]		long (cohesive)	short	short	short	very long	long (cohesive)
Paste clarity		Slightly cloudy	opaque	opaque	opaque	clear	clear
Tendency to gel/retrograde		very low	very high	high	high	medium to low	medium
Lipids (%dmb)	0.4	0.2	-	0.8	0.9	0.1	0.1
Proteins (%dmb)	0.4	0.25	0.5	0.35	0.4	0.1	0.1
Phosphorus (%dmb)	0.09	0.00	0.00	0.00	0.00	0.08	0.00
Flavour		clean		cereal (slight)	cereal slight	slight	bland

Notes Sourced from BeMiller and Huber (2008)
a) From the initial temperature of gelatinization to complete pasting
b) Under ordinary cooking condition, where the slurry is heated to 95-100°C, high- Am corn-starch produces essentially no viscosity. Pasting does not occur until the temperature reaches 160-170ºC
c) Viscous solutions with shear-thinning pseudo plastic behaviour are called “short flow” and with little or no shear-thinning are called “long flow”.

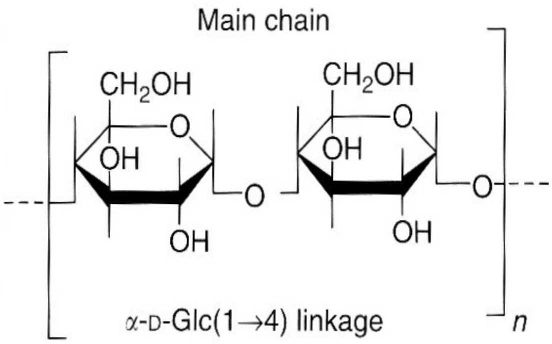


Figure 2.3 Structure of Am

Note Sourced from Chibbar and others (2004)

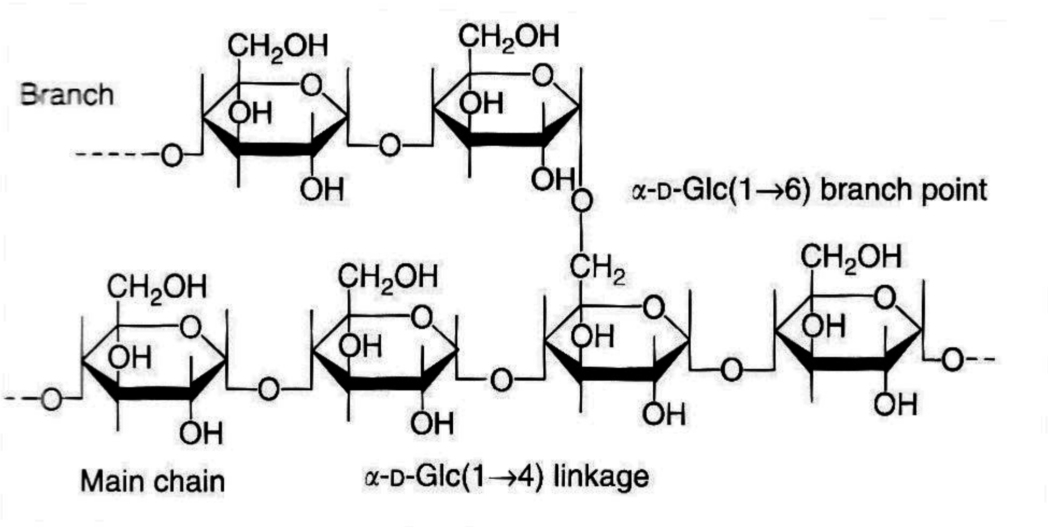


Figure 2.4 Structure of Ap

Note Sourced from Chibbar and others (2004)

Am and Ap do not exits freely but as combined discrete particles called starch granules. The packaging of these two components is organised which is interwoven throughout the crystalline and amorphous areas (Figures 2.5 and 2.6) and when starch granules is heated in the presence of water, the starch granules become less ordered. The loss of orderly clusters of starch occurs at different temperatures depending on the type of starch and starch swells until its structure disintegrates and Am and Ap are completely released into the aqueous phase.

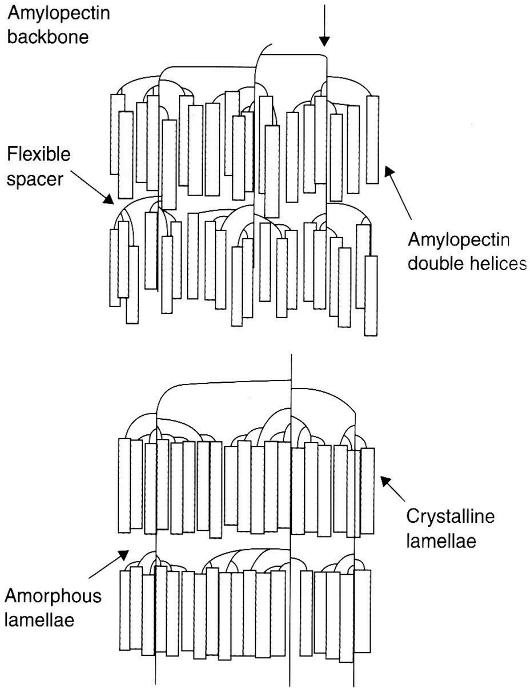


Figure 2.5 A cluster model for Ap

Notes 1 The shaded blocks represent double helices. They are disordered in the dry state (top), but aligned in the hydrated state (bottom).
2 Sourced from Donald and others (2001)

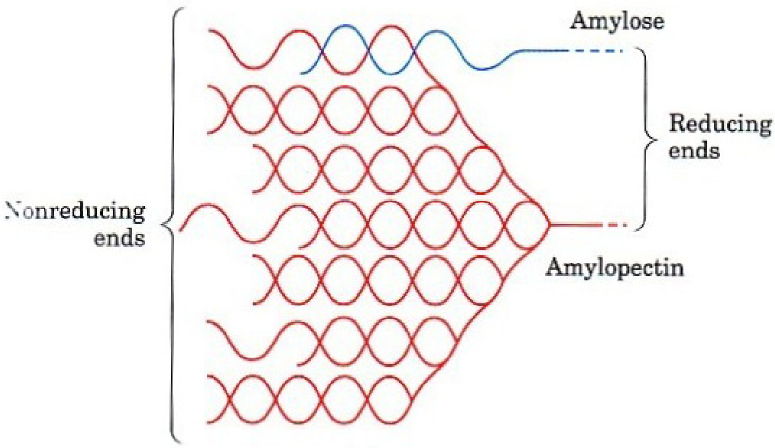


Figure 2.6 A cluster model for starch

Note Sourced from Nelson and Cox (2000)

2.6 Other chemical components of the rice grain

There are two other major chemical components of the rice grain and these are water and protein. Water content will vary depending upon the conditions applying at harvest and also during storage of the grain with typical values of approximately 14%. The protein content of milled rice varies from 6.6 to 15.2% dmb depending on the rice variety (Zhou, Robards, Helliwell and Blanchard 2002). The protein content of isolated rice starch is generally 0.5% or less although it can be variable in between 0.5% to 0.61% depending on the method of isolation (Singh and others 2000). There are a number of distinct proteins found in rice, and the relative proportion of these is a varietal characteristic and also depends on whether the rice has been milled. The four main protein fractions that have traditionally been identified are described on the basis of solubility in a series of solvents as follows: albumin (water soluble), globulin (soluble in salt solutions), prolamin (alcohol) and glutelin (alkali). The corresponding fractions of rice proteins are 9.7-14.2% albumin, 13.5-18.9% globulin, 3.0-5.4% prolamin and 63.8-73.4% glutenin. In contrast, brown rice contains 18.8-20.8% albumin plus globulin, 12.5-14.5% prolamin and 66.0-67.7% glutenin.

The lipid or oil content of brown rice constitutes approximately 2.2% (dmb) and this is found to be distributed as 51% in germ, 17% in endosperm and 32% in polish (Zhou, Robards, Helliwell and Blanchard 2002).

2.7 Rice varieties

As with most crops, farmers grow particular genetic types each of which has its own unique combination of genetic material. Each of these types is known as a variety or cultivar and rice varieties are primarily divided on the basis of grain size and shape into three types, known as short, medium and long grain. The general physical characteristic of rice grain is presented in Table 2.2. Each of these is associated with specific milling, cooking and processing characteristics. Long grain varieties are preferred for parboiling, canned rice, quick cooking rice, in frozen dishes as well as when boiled or steamed. Short and medium grain types, cook to give moist and chewy characteristics and are preferred for manufacture of breakfast cereals, baby foods and are also used in the brewing industry.

The grains of most rice varieties are also described as translucent, non-scented, non-waxy (common) type which contain varying ratios of Am and Ap and are considered to have bland taste. Another category of rice is waxy (glutinous) rice, also called "sweet rice" and this is characterised by opaque endosperm containing predominantly Ap molecules. Waxy rice starch has an apparent Am content of 0.8-1.3% and this is probably located at the hilum (centre) of the granule, although some rice (waxy rice) genotypes contain essentially no Am. On the other hand, non waxy milled rice may have 7-33% the Am and such values are used to classify milled rice with generally accepted ranges being waxy, 1-2%; low, 7-20%, intermediate, 20-25%; and high, > 25% (Eliasson 2004).

Table 2.2 General physical characteristics of rice types

Grain type	*Length (mm)*	*Length: width ratio*	*Weight (mg)*
Long-grain	6.61 to 7.5	over 3	15-20
Medium-grain	5.51 to 6.6	2.1 to 3	17-24
Short-grain	up to 5.5	up to 2.1	20-24

Note Source of data used was Juliano (1985)

2.8 Milled or white rice

Firstly, the production of brown rice involves the removal of the husk and then during processing the bran layer is abraded removing approximately 8-10% of the weight of the brown rice. The material known commercially as bran consists of the testa, cross cells, aleurone cells, part of the aleurone layer and the germ and includes almost all the oil of the rice caryopsis. As the bran layers include cells which remain metabolically active, lipases and other enzymes, particularly from the testa and cross cells are able to promote rapid hydrolysis of substrates under certain circumstances resulting in undesirable changes. Among these include the development of hydrolytic rancidity where acylgycerol components are present and suitable precautions may be applied to limit such changes during processing.

Milled/white rice is slightly smaller in size than brown rice, its outer surface is smooth, non-glistening and waxy white and each of the flat surfaces has two inconspicuous parallel ridges. The contents of some of the surface endosperm cells are exposed as a result of the removal of cell walls. It has been reported that the specific gravity of milled rice ranges between 1.43 and 1.47 at 30 °C and 12% moisture (Houston 1972; Juliano 2004).

2.9 Criteria of rice grain quality

2.9.1 Ageing of rice

Ageing of rice is a complex natural phenomenon that involves physical and chemical changes to the rice characteristics and these may involve reactions catalysed by enzymes which are also present in the rice. The cooking quality depends on the starch, protein and lipids present in rice and their interaction with each other. A major change occurs in the pasting properties during ageing of rice and this is influenced by both the temperature and length of the storage period. The changes are attributed to changes occurring within the starch granules and it is well established that those of stored rice are more resistant to swelling than are those of freshly harvested rice (Zhou, Robards, Helliwell and Blanchard 2001).

Rice lipids undergo changes during ageing and storage of rice due to hydrolysis and oxidation. Although the protein components are less subject to change during storage, there is a decrease in the relative amount of the albumin protein and there is an increase of free amino acid contents in milled rice. Other minor rice components including phenolic acids, which contribute in the mechanical properties of cell walls, increase during storage of milled rice and thereby partly contribute to the cooking properties of aged rice (Zhou, Robards, Helliwell and Blanchard 2001).

A previous study shows that ageing of rice for a period of one month and also for twelve months results in no discernable changes in total starch, protein or moisture content with storage. However, the molecular weight of the glutelin doubled; the Am content increased a little and its molecular weight decreased slightly; the Ap molecular weight increased marginally while the stickiness decreased. The changes in starch were attributed to enzymatic activity. In addition the number of disulfide bridges (S-S) increased with storage due to oxidation of the glutelin. There was an increase in the cystine content of storage protein oryzenin/glutelin from 0.12 to 0.22% in medium grain- rice and a decrease in cysteine content of oryzenin/glutelin from 0.20% to 0.14% after storage. A similar trend was found for long- grain rice (Chastril and Zarins 1992).

2.9.2 Chalky rice

Some non-waxy varieties of rice have a chalky portion present in the endosperm. When the chalky region extends to the centre of the endosperm and to the embryo (edge of the ventral side) of the rice, this is called white core. The term white belly is applied to describe grains in which there is an opaque region in the middle of the embryo (ventral side). A long white streak on the dorsal side is referred to as white back. These various forms of chalkiness in rice are thought to be due to the loose packing of the starch granules in the region which appears to be chalky (Juliano 1985). In contrast, waxy rice has an opaque endosperm and the starch granules are compound and closely arranged except at the ventral side.

Chalky rice grains occur mainly due to unfavourable environmental conditions and when the rice is harvested too early so that immature kernels are present. In some varieties, the panicles do not mature uniformly and this can also lead to problems seen as chalkiness. The type of chalk (location of the chalky spots on the endosperm), and the amount of chalk are very important during processing. These affect the milling which leads to excessive breakage of rice kernels and excessive chalkiness also results in over processing of rice kernels during parboiling. Visual examination is the primary approach used to determine the amount of chalk in rice grains (Juliano 1985).

2.9.3 Rice stickiness

The stickiness is observed as a change in the texture of cooked rice during cooling and storage and is due to small particles present on the rice surface. These particles contain glutelin and starch, and stickiness also appears to be influenced to some extent by albumin and globulin proteins. Typically, stickiness or cohesiveness of cooked aged rice is less than that of freshly harvested rice and is particularly caused by chemical and physiochemical changes in oryzenin. Some of the factors include molecular weight, cystine bridges, the composition of peptide units as well as the Am and Ap fractions of the rice grain. The amount of Am appears to be significant but the most important factor was found to be binding of glutelin protein and starch components. There was a linear correlation between stickiness and the equilibrium binding constant obtained by calculating absorbance values and the stickiness was also inversely related to the molecular weight of the glutelin (Chastril 1990).

2.9.4 Crushing of rice

Regardless of the cereal grain type, the grains comprise a fibrous external shell called bran, an internal starch portion called endosperm as well as the germ. During processing applied to any of the cereal grains, the exterior parts of the grains are fractured in some way. So for example, this takes place during milling of the wheat grain to produce flour or rolling in the case of oat grain processing. In the puffing of cereal grains, the process occurs in the equipment used for production and crushing of the whole grains tends to minimise the need for an extended soaking time prior to processing. The creation of cracks in the structure of the surface of the whole grains results in increased water absorption while facilitating subsequent gelatinization of the starch granules (Westercamp 2010). Currently, there is a very limited amount of literature which clarifies the role and significance of crushing during puffing of cereal grains.

2.10 Physical, mechanical and thermal properties of rice

2.10.1 Moisture content

Rice is a hygroscopic material and during the process of movement or transportation from one environment to another, the grain very readily absorbs moisture from the air although under conditions of low humidity, loss of moisture can also be observed. In the achievement of an equilibrium state, moisture diffuses readily throughout the hull, bran and endosperm of the grain.

2.10.2 Water uptake ratio

Water in cereal grains, and starches extracted from them, can be present in several forms and these include:

(a) Free water: this water is **absorbed** and it may be present in intercellular and intergranular spaces where it may be held by capillary forces;

(b) Bound water: this is **adsorbed:** it interacts with the starch molecules, influencing starch properties; it is held by molecular attractions (4-15 kcal per mole) and is harder to remove than free water. **Sorption** and **desorption** are terms used to describe the addition and removal of this bound water; and

(c) It may also be present as chemically bound water, where it is bound by covalent or ionic bonds (> 50 kcal per mole) (Reid and Fennema 2008).

Bound water is defined as water that does not freeze on cooling. If cold water penetrates the amorphous regions a maximum water content of approximately 30% can be obtained under normal atmospheric conditions in cereal starches (Reid and Fennema 2008). Under ambient conditions these starches usually have a moisture content of 12-14%. A number of other properties of the starches depend strongly upon moisture contents (Trommsdorff and Tomka 1995). It has also been reported that the water absorption rate of milled rice during soaking decreases sharply at temperatures below 20°C (Okuno and Adachi 1992).

2.10.3 Gelatinization temperature

When heated, starch undergoes an irreversible transition called gelatinisation and for gelatinisation to occur the amorphous fraction of starch must be above its gelatinisation temperature. During heating the starch intra-molecular hydrogen bonding is broken, the grain absorbs more water and swells, and as a result, the swelling of starch causes loss of birefringence. The temperature at which the granules begin to swell rapidly and lose birefringence is called the gelatinisation temperature. After gelatinisation the starch crystallinity is reduced to zero and Am is leached out of the granule structure as it loses its integrity. When the temperature of a starch suspension is increased above the gelatinisation range, the granule continues to swell, if sufficient water is present. Additional swelling increases the viscosity as the swollen granules begin to collide frequently. The viscosity change depends on the temperature, initial concentration of the starch suspension, the granule size and the effect of other ingredients in the system.

Gelatinisation can be studied by DSC, X-ray scattering, light scattering, thermo-magnetic analysis, nuclear magnetic resonance and by using rheometers. There is no consensus about the relationship of starch structure and thermal properties. Enthalpy changes during gelatinisation may be due to loss of helical structure order rather than changes in crystallisation. Other work suggested that it relates to changes in crystallinity of the Ap (Gunaratne and Corke 2004).

2.10.4 Pasting properties of starch

The continuation of heating of starch granules beyond that of the gelatinisation temperature, in the presence of excess water, results in further granule swelling; there is an additional leaching of Am and eventually the total disruption of starch granules occurs due to the shear forces imposed during the testing of the samples. This result in the development of a starch paste also referred to as a starch slurry. A viscous paste is produced and this consists of a continuous phase of solubilised Am and/or Ap along with a discontinuous phase of starch fragments. Complete molecular dispersion does not occur, except under conditions of very high temperatures, high shear and excess water. Subsequent cooling of a starch past results in a viscoelastic, firm and relatively rigid gel-like structure (Gunaratne and Corke 2004).

2.10.5 Starch retrogradation

The term retrogradation describes the changes which take place when a heated starch paste is cooled below its crystallisation temperature. It is measured using a DSC, a rheometer or gel hardness tester. During the cooling, Ap molecules reassociate with Am and a resultant increase in viscosity is observed. It is considered that re-crystallisation has occurred corresponding to the aggregation of double helices. It is believed that Am is responsible for the short-term changes (for periods of less than a day) and the majority, occurring over a longer time (several weeks) is due to Ap. Hydrogen bonding may be responsible for re-crystallisation: intramolecular (between Ap OH-6 and the adjacent hemi acetal oxygen of the D-glucosyl residues; and intermolecular bonding between Ap OH-2 and Am O-6 (BeMiller and Huber 2008).

2.11 Processing of rice based puffed products

Previous studies on puffed rice indicates that processing variables affect the overall quality and consumer acceptability of the finished products. It has been suggested that puffing is effectively a measure of the expansion ratio (Hoke, Housova, & Houska

2005). However, although the composition and changes in the major components of rice have been reported in detail, little has been presented in the scientific literature on the puffing process. It is therefore a gap in current knowledge and requires study to find out more about the influence of processing conditions and factors which contributes to quality of puffed rice products. In the context of the relatively little research carried out into puffing and adhesion of rice grains, the next chapter focuses on the studies done on various cereals, and in particular rice grains, for the manufacturing of puffed cereal products.

Chapter 3

Background and literature review: manufacturing, physical and mechanical properties of puffed products

The purpose of this chapter is to briefly describe processes applied in the manufacture of puffed products from cereal grains. This focuses on the use of rice for puffing, the use of different processing methods and equipment as well as the physical, chemical and textural characteristics of the resultant products.

3.1 The process of making rice cakes

The puffing of cereal grains involves the application of heat to pre-moistened grains for a short period and the equipment typically used in the production of rice cakes is shown in Figure 3.1 (Hsieh 1989). This allows for the application of pressure as well as heat that contribute to the development of adhesion between the individual grains of rice.

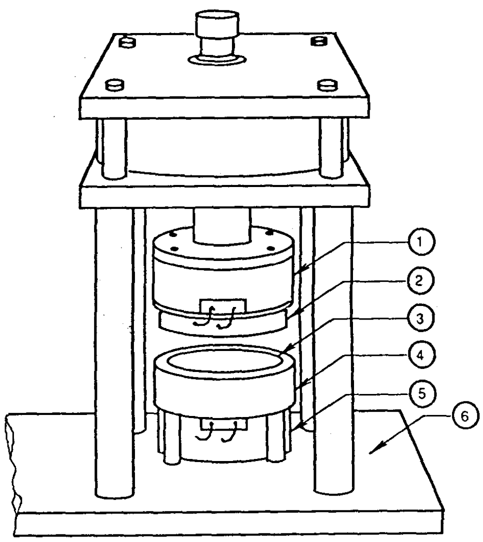


Figure 3.1 Equipment used in processing of rice cakes

Notes Figure sourced from Hsieh and others (1989)
1 insulation block
2 upper platen
3 lower platen
4 ring
5 insulation block
6 base plate

The mould consists of main three parts: a ring - shaped side piece and two moveable platens. The mould is preheated to a temperature within the range of 200 to 260ºC. Steeped rice is placed on the lower platen inside the ring, then the upper platen is moved downwards to crush the rice lightly and at the same time the rice will be heated from top, bottom and sides. The initial heating period is very brief, corresponding to several seconds, after which the upper platen is moved upwards to allow space for the rice grains to expand. Very rapidly the puffed rice grains expand to fill the mould (within a few seconds). They are slightly constrained and compressed together so that the surfaces of a grain will stick to those of adjacent grains. Upon completion of this cycle, the ring and platens are moved so that the cake can be swept out of the mould onto a conveyor. The rice cake will start to cool in the ambient conditions as it passes along the conveyor towards the packaging station.

3.2 Studies on the influence of processing conditions on production of rice and other cakes

Whilst there have been relatively few studies in this area, it has been established that tempering and heating conditions are important determinants of product appearance and overall quality. The puffing of rice cakes has been studied using a series of processing variables including tempering conditions (time and moisture level) and heating (temperature and time). The results showed that a lower moisture level (14% rather than 16-20%) in raw rice and longer tempering times (5hr in comparison with 1-3hr) resulted in higher specific volumes in rice cakes. The higher heating temperature (230°C compared to 200-220°C) in conjunction with a heating time of eight seconds produced rice cakes with higher specific volume. Darker product colour was observed for combinations involving higher temperatures and longer times (Huff, Hsieh, Peng and Marek 1989).

In further trials it was found that rice cakes made from long grain brown rice showed a greater specific cake volume at lower moisture, higher temperature and longer time and medium grain brown rice showed a greater specific rice cake volume at high tempering moisture. In general, the specific volume of long-grain rice cake appeared to show a decreasing trend as moisture was increased from 12 to 20%. On the other hand, for cakes prepared from medium grain rice, specific volume increased steadily from 7.31 to 8.42 mL/g as moisture was increased from 12 to 16%. An increasing trend was observed in the specific volume of rice cakes as the heating temperature applied was increased from 210 to 230°C. Medium grain brown rice also produced cakes that were much more fragile than those from long grain brown rice. The colour of the rice cake correlated well with density: the higher density cakes had a lighter colour (Huff, Hsieh, and Peng 1992).

In a subsequent report, the puffing of wheat using the same rice cake equipment showed that specific volume increased with increases in moisture content, tempering time and heating time. The hardness of wheat cakes decreased as moisture content and tempering time increased and also increased as temperature and heating time increased (Fan, Hsieh and Huff 1999).

In a more recent study, rice grains which had been coated with flavouring agents were used and flavour retention during puffing was evaluated. It was found that the rice coating procedures used were effective in uniformly distributing and preserving flavour during puffing and storage. In addition, the rice cakes made from coated grains had enhanced mechanical properties (Klamczynski, Glenn, and Orts 2002).

The incorporation of black rice on puffed rice cakes has also been investigated (Lee, Kim, Hsieh, and Eun 2001). Combinations of black rice with medium-grain brown rice were trialled with up to 75% black rice content, using a rice cake machine. The conditions used were: puffing temperatures 250, 260 and 270°C, puffing times 5, 6 and 7 s along with conditioning moisture levels of 16, 18 and 20%. It was found that the specific volume of the rice cakes increased and reached a maximum at 18% moisture when puffing time and temperature was increased. Two maximum values for cake hardness were found, at 250°C and 260°C for 6 seconds at 16 and 20% moisture respectively. The products had a lighter colour with decreasing moisture content, temperature and time. Redness and yellowness components of colour increased with increasing temperature and time. Cake robustness, measured by weight loss during tumbling, showed an increase in robustness or integrity with increasing heating time, temperature and black rice content (Lee, Kim, Hsieh, and Eun 2001).

Combinations of wheat starch and rice grains were evaluated in processing using rice cake equipment, in order to study the effect of wheat starch on the textural properties of puffed brown rice cakes. The modified cakes heated for 10s at 210ºC exhibited greater flexibility and fracture strength than traditional rice cakes. The density decreased with increasing moisture content independently of particle size (particle size ranged from 0.8 - 5 mm) (Orts, Glenn, Nobes, and Wood 2000). These authors did not comment on the mechanism of puffing or adhesion.

3.3 Studies on production of rice cakes and puffed rice using alternative equipment

A new method for production of puffed cereal cakes, in particular those made from rice, had been proposed using ultrasound (Capodieci 1999). This approach allows processing of puffed cereal cakes while facilitating the incorporation of temperature sensitive ingredients. Puffed or un-puffed cereal grains are moulded under pressure using ultrasound which contributes by bonding of the cereal grains to form a more solid cake. As a result there is reduced fouling of the mould and corresponding increases in the production rate. In one application of the method, pre-puffed cereal grains were coated with a binding agent and were then bonded together at low temperature using ultrasound. It was reported that the method can also be used to make puffed cakes with shaped or profiled surfaces (Capodieci 1999).

In a more recent study the effects of puffing by injection of steam under pressure has compared for a variety of different cereal grains. These included common wheat, emmer wheat, rye, barley, buckwheat and rice, and the conditions involved pressure of 1.3-1.5MPa for 75-85 seconds in an expansion chamber. A further comparison included the use flours milled from the same grains and the data showed that the puffed grain quality depended strongly on the composition of the kernel. Puffed rye and rice had a very porous matrix made up of numerous cavities of different sizes separated by thin ‘walls’. Puffed wheat and barley on the other hand had a much more compact, homogeneous and less porous structure whereas puffed buckwheat had a large number of small and regular cavities. Puffing induces significant changes in the structure and physical properties of starch and an increased water holding capacity of both the grains and the flours (Mariotti and others 2006).

Milled and brown samples for three cultivars of rice (Kaohsiung sen 1, Tainung 67, Taichung waxy 70) having different Am contents (1.0, 20.3, and 32 % respectively) were studied for physicochemical characteristics of expanded products using a traditional explosion-puffing process. Explosion-puffed rice was highly expanded, with a net-like inner structure and the data demonstrated that degradation of Ap had occurred. Water absorption index, water solubility, swelling power and degree of gelatinisation were increased by explosion-puffing. Rice with high Am content was found to be unsuitable for preparing the explosion-puffed product. Its expansion ratio was much lower than the cultivar with low Am content rice and the waxy cultivar. Brabender Viscoamylograms of the processed rices were different from those of the raw rices and also differed among rice varieties. Waxy products exhibited higher initial viscosity values and showed a decline in viscosity during heating. Non-waxy samples with lower initial viscosity increased in viscosity during heating and tended to be stable. The waxy product revealed an amorphous X-ray diffraction pattern. A further finding of this study was that there were no significant differences between the nature of products made using brown and the corresponding milled rice samples (Chang and Chang 1995).

In an investigation of twenty-five varieties of rice the popping expansion properties were analysed on the basis of the chemical and physical properties of the rices. It was found that the content of Am and protein, as well as the hydration capacity and gelatinisation temperature of brown rice have no relation to popping whereas the rice grain hardness, the absence of white belly and rice surface cracks enables good popping (Murugesan and Bhattacharya 1991).

In an earlier study, different methods of processing were applied prior to gun-puffing of rice and puffing in oil. The treatments included parboiling and pre-gelatinisation of milled rice, and these were used to study varietal differences influencing quality characteristics of puffed products. The results showed that completely gelatinised rice grains, when cooked in excess water or parboiled at high steam pressure, puffed well regardless of Am content. In the presence of limited amounts of water, the volume of puffed rice showed dependence on rice starch gelatinisation temperature and Am content. Waxy rice gave the best puffed products with the gun puffing method and the quality was influenced by the Am content. Low and medium Am content resulted in gun puffed products that were preferred in terms of texture. It was also concluded that high protein content in the grain tends to inhibit the puffed volume expansion (Juliano and Villareal 1987).

3.4 Review of studies on the mechanical properties of puffed and extruded products

Although there have been a limited number of reports in this broad area, various aspects have been reported during the past two decades. These have involved the use of a number of different approaches to the evaluation of textural attributes of the products.

For puffed rice cakes, mechanical measurements showed that the compressibility of dry cakes follows the general pattern expected for cellular solids, i.e. their stress- strain relationship has a characteristic sigmoidal shape (Laurindo and Peleg 2007). The effect of water activity on textural characteristics of puffed rice cakes has also been investigated using a break test and this showed that the maximum peak force for hardness was observed with water activities ranges between 0.44 to 0.65. It was suggested that a water activity of 0.44 represents a critical point for rice cake texture (Hsieh, Hu, Huff and Peng 1989).

Many of the other relevant studies on the expansion of cereal and starch-based materials have been carried out on extruded materials which form foams. According to Lin, Huff, Parsons, Iannotti and Hseih (1995) the moisture sorption isotherm showed a sigmoidal shape during the determination of the effects of water activity on the mechanical properties of extruded foam prepared from high Am corn starch. The stress- strain curve was found to be linear with an increase seen for higher moisture samples as compared to curves for samples at lower moisture levels. Increases in the water activity (0.53-0.75) caused the foams to soften and thus decreases were found in the spring index.

In a study on cellularity, mechanical failure and textural perception of corn meal extrudates, it was found that the influence of cellularity and bulk density is a combined effect: cell area increased with an increase in bulk density. Fracturability of extrudates was negatively dependent on mean cell size and positively related to bulk density (Barrett, Cardello, Iesha and Taub 1994). The structure and mechanical properties of extrusion-cooked maize foams indicated that when the foam solidifies during the step of extrusion-cooking, the foam had closed cells which were polyhedral in shape. The variation of the glass transition temperature with foaming conditions influences the shape of the foam cells as does the mechanical strength (Warburton and Donald 1992). The mechanical properties of extrusion-cooked maize showed that the shape of the cells in maize foams changes with foaming conditions: non-equilibrium spherical cells are formed at low moisture content as well as high temperatures (Warburton, Donald and Smith 1992).

For pure corn extrudate, breaking and plateau stresses correlated strongly with both density and average cell size and was considered to be the main indicator of extrudate strength (Barrett and Peleg 1992). Yet another study was done on the cell size distribution of puffed corn extrudate and it was found that mean values as well as degree of skewness, were characteristic of the extrudate type and its particular cell structure (Barrett and Peleg 1992). The study on deformation of brittle starch foams showed that the cell wall properties vary with the extrusion conditions, in particular, the density and crystallinity (Warburton and Donald 1990).

The effect of salt, sugar and screw speed on processing and product variables of corn meal extruded with a twin-screw extruder showed that the addition of salt and sugar enhanced radial and axial expansion whereas increased screw speed decreased the effect. The addition of salt and sugar reduced the product bulk density and breaking strength (Hsieh and others 1990).

In summary, past studies do not fully explain the mechanism of puffing and adhesion of rice grains and very limited work has been done on the puffing of rice for preparation of rice cakes. The data on extruded foams provides some insights which may be useful to the development of an understanding of the adhesion properties of rice grains during puffing. However again there have been relatively few definitive studies on these topics.

There is another possibility that may be useful here: that is to investigate another area of puffed products which has been the subject of considerable research. Specifically, more is known of synthetic polymers which may well have the same principle of puffing as that of cereal grains. In this context, the following chapter describes the basis of the studies reported on puffing of synthetic polymers and their link to the study reported in this thesis with the puffing of cereal grains.

Chapter 4

Background review: synthetic polymers

The purpose of this chapter is to provide background and review current knowledge on synthetic polymers. The areas covered include a brief overview of the morphology and chemical composition of these polymers and their application in preparation of foams, along with a brief comparison with the puffing of rice.

4.1 An overview of general characteristics of synthetic polymers

4.1.1 Polymer types and their chain configuration

A polymer is a substance composed of molecules made of more than one repeating unit linked together by covalent bonds. Polymers are distinguished by the presence or absence of cross links. Thermoplastics can be repeatedly heated, shaped by pressure and are cooled to retain the shape. Thermoplastics are primarily governed by secondary van der Waals forces, dipoles and hydrogen bonds exist between the chains (Moore and Kline 1984). Another group of polymers are the Thermosets and these are materials that can be heated, shaped by pressure, removed from a hot mould without cooling in a non repetitive process and additional heat and pressure results in degradation. In general, a thermoplastic can be considered as a non crosslinkable polymer, while a thermoset is cross linked polymer. Thermoplastics can be processed using conventional processing techniques such as extrusion, injection moulding and compression moulding. An example of a thermoplastic is polystyrene (PS) and products may be either solid or alternatively foamed if a blowing agent is added.

Molecular weight of the polymer plays an important role in determining the physical properties including temperature for transitions from liquids to waxes, to rubbers to solids. The mechanical properties particularly stiffness, strength, visco-elasticity, toughness and viscosity also depend on the molecular weight of the polymer. The chains can have various configurations and may be atactic, syndiotactic or isotactic. Isotactic chains have the most regular configuration: during polymerisation, each monomer unit is added to the main chain in the same orientation, so for example any bulky side group is always on the same side of the chain. Syndiotactic is the next most regular: during polymerisation each monomer unit is added in the opposite way to the previous one, so for example placement of a bulky side group alternates sides of the chain. Atactic is the most irregular; monomer units are placed at random orientation along the chain.

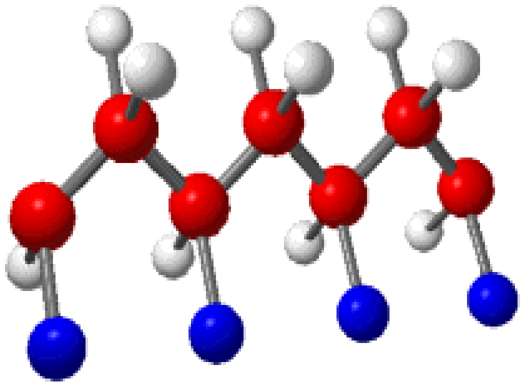


Figure 4.1 The molecular arrangement of an atactic polymer
Note Sourced from Encyclopaedia Britannica (2011)

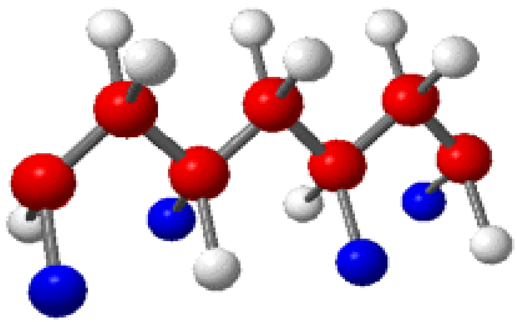


Figure 4.2 The appearance of a syndiotactic polymer
Note Sourced from Encyclopaedia Britannica (2011)

4.1.2 Morphology of polymer

An amorphous polymer contains no crystals and also whether a polymer crystallises or not depends on a number of factors, including molecular architecture and rate of cooling. A polymer may be atactic if its molecules are irregular, bulky, having long side groups or, alternatively they have a rigid chain or are highly branched and tend to be amorphous. Molecules with a high degree of cross-linking generally do not crystallise. Polar polymers are less likely to be amorphous (Gedde 1995). The glass transition temperature of an amorphous polymer is presented in Figure 4.3 and illustrates the crystalline and melting behaviour of the polymer. As temperature decreases the specific volume decreases as atoms in a molecule move closer together. At a certain point the atoms in the molecules are so close, further contraction on cooling becomes more difficult. This point is referred to as the glass transition temperature (Sperling 2001).

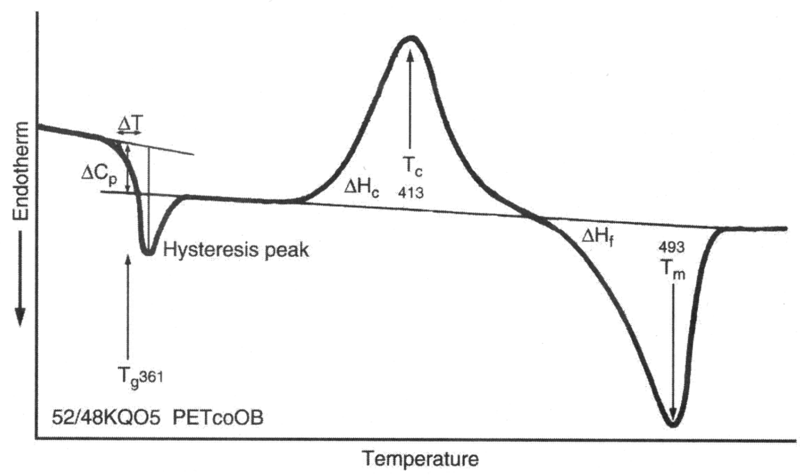


Figure 4.3 Glass transition temperature in polymer
Note Sourced from Sperling (2001)

A crystal is a portion of matter where the atoms are arranged in a regular, repeated, three dimensional periodic patterns (lattice). The repeating period of the lattice that most simply describes the nature of the lattice is called the "unit cell". The latter may take up various shapes, depending on the atomic arrangements of molecules, and examples are monoclinic, orthorhombic, and cubic and the shape reflects the lowest energy state for the material. However, some polymers may form two crystal forms at equilibrium, and in these instances the term are called "polymorphic" is used. Isotactic polymers tend to have the highest crystallinity, atatic the lowest and the degree of crystallinity varies from a few percent (~20% in low density polyethylene) to high values (~80% in high density polyethylene).

Crystallinity of a polymer describes the extent to which the molecules are present in an ordered structure rather than an amorphous arrangement. Crystallinity influences many of the polymer properties including hardness, modulus, tensile strength, stiffness, crease and melting point. In the case of starch, Ap contributes to the crystallinity and occurs as packed double helices as described in Figure 2.5 and 2.6 of chapter 2. The packing together of these double-helical structures results in the formation of crystalline lamellae.

4.1.3 Polymer blends

Polymer blends exhibit complex behaviour due to the particular viscoelasticity characteristics of the phases. Polymer blends may be miscible or immiscible and those that are miscible consist of solutions and homologous polymer blends and are single phase mixtures. The immiscible blends consist of suspensions, emulsions and block copolymers and are two phase mixtures. The morphology of both miscible and immiscible polymer blends are influenced by factors such as composition, viscosity ratio of the molten components, melt elasticity ratio, interfacial tension and processing conditions (Moore and Kline 1984).

Starch based plastic foams are one of the common types of polymer blends. Food starches such as corn, wheat, potato and rice may be blended with various polymers including polyethylene vinyl alcohol (PVOH), cellulose acetate (CA), polystyrene, and poly lactic acid (PLA) (David 2004). Blending of polymers can result in enhanced processing and mechanical properties. The improvements depend on controlling the morphology of the blend and increased Am content (particularly for starches extracted from maize, potato and pea) increased the tensile strength (40-70 MPa) and elongation (4-6%) of unplasticised films (Willet and Shogren 2002).

4.2 Thermoplastic polymers

Many types of polymers can be “foamed”, especially thermoplastics and rubbers. Thermoplastics are the polymers that soften or melt on heating and become rigid again on cooling and these are different from thermosets, which cross-link on heating. An example of a thermoplastic is polystyrene (PS) and such polymers are often produced as foams for use in a wide variety of applications and industries. In a single step process, the thermoplastic is heated then mixed with a “blowing agent”; the mixture is then cooled and depressurised and foaming occurs. In a two step process, the thermoplastic is soaked with blowing agent, and then rapidly cooled: on reheating above the softening point, foaming occurs.

There are two classes of blowing agents, chemical and physical. Chemical blowing agents commonly include azodicarbonamide and bicarbonate of soda. These decompose on heating to CO_2 and H_2O. Physical blowing agents are usually low boiling point; low viscosity liquids, such as chlorofluorocarbons or hydrocarbons and these are used in their liquid form for easier handling and mixing. Thermoplastic foams can be made by most of the conventional processing techniques including extrusion; injection moulding and compression moulding.

4.3 Compression moulding

Compression moulding involves placing a measured mass of polymer/blowing agent mixture into a heated closed mould under pressure. The pressure is reduced and foaming occurs: the mixture expands to fill the mould cavity after which the product is removed from the mould. The compression moulding of a polymer is illustrated in Figure 4.4.

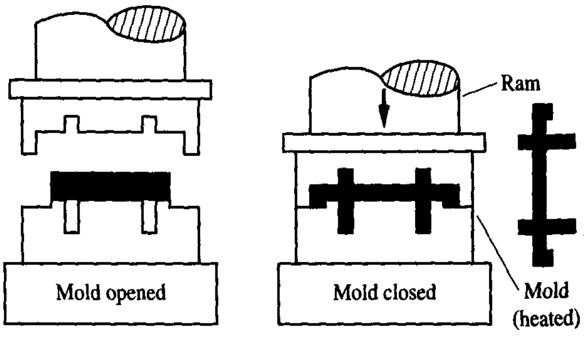


Figure 4.4 Compression moulding of synthetic polymer
Notes 1 The figure specifically operation of compression mould
2 Figure sourced from Griskey (1995)

Thermoplastic foams are prepared using a physical blowing agent is made by saturating the polymer with the agent under conditions of high pressure and temperature. The blowing agent is typically very soluble in the thermoplastic so diffusion is sufficient to create an intimate mixture, otherwise mechanical mixing may be required. The mixture is then subjected to a thermodynamic change including a temperature decrease and pressure drop. The blowing agent changes state and diffuses out of the polymer causing bubbles to grow, creating a cellular structure characterised by a particular cell size and foam density. Physical blowing agents are either mixed with the polymer or allowed to diffuse, depending on the polymer process to be used to make the foamed product. Moulding processes are either single stage, including extrusion or injection moulding, or multi stage, such as compression (Gendron 2005).

4.3.1 The process of single-stage foaming

In the single-stage process a liquid blowing agent is preferred: it is easier to mix with the polymer than a gas. The polymer is heated under pressure to a temperature above its melting or softening point. The liquid blowing agent is injected into the barrel and is mixed with the polymer with the aid of mechanical mixers and intense mixing achieves homogeneity. The best quality of products is achieved with foams made with blowing agents that are readily soluble in the polymer. Chlorofluorocarbons and hydrocarbons have high solubility in most polymers, whereas carbon dioxide, water and nitrogen have low solubility. The mix is subsequently cooled to a temperature close to the softening point of the polymer and the mix is depressurised. The liquid blowing agent then nucleates cells (bubbles) and diffuses from the polymer into the growing cells forming a gas. The phase change cools the growing cells, which increases the viscosity and strengthens the cell walls. The molecules orient within the cell wall as the bubbles grow and the orientation is fixed by the cooling of vaporisation. Eventually the cell walls become so strong that the blowing agent diffusing into the cell no longer generates sufficient pressure to cause the cell to grow further. The density of the foam is then at a minimum. When the foam cools the gas in cells contracts: the density increases slightly. And it is important that the foam does not collapse during cooling. This problem may occur due to the slight vacuum in the cell if contraction exceeds the diffusion rate of blowing agent into the cell. As the foam ages it is important that the pressure in the cells is maintained: diffusion of air into the cell should be approximately the same rate as the diffusion of blowing agent out of the cell. “Ageing” occurs for a few days or weeks until the cells only contain air. When the air pressure in the cells reaches equilibrium, the density of the foam and dimensional stability will be constant.

4.3.2 Multi-staging foaming processes

In a multi-stage process the polymer is saturated rather than mixed with a blowing agent which must have high solubility in the polymer. An example of multi stage foaming is “expandable polystyrene” (EPS) and for this pentane is used as the blowing agent. EPS is made in several stages: PS is saturated with pentane; the beads are pre-expanded, aged and then moulded. During pre-expansion the EPS is heated with steam in a vacuum (0.5 bars) for a pre-determined period of certain time: the beads expand to a low density of 1.06g/cm^3 (Sperling 2001). These are usually done as a batch process and during ageing the beads are placed in nets to allow diffusion of the pentane out of the bead and to allow air to enter. The intermediate ageing process can be 4 to 36 hours at ambient temperature. In the moulding stage, moulds are filled with a closely controlled mass of beads. The mould is heated with steam, which softens the PS as it has a glass transition temperature of ~ 70ºC. Over-packing causes neighbouring beads to be pushed firmly together so that the beads become squarer in shape and have relatively large areas of surface contact with neighbouring beads. The application of heat and pressure allows adhesion (welding) to occur between neighbouring beads. PS is amorphous so the welding between beads is achieved by diffusion of molecules from one bead into the next. Molecular diffusion is possible only when the temperature is above the glass transition. Under these conditions some molecules will entangle with neighbouring molecules, creating a weld. Once the polymer cools below its glass transition, the molecules freeze and further movement is prevented and as a result, the molecules will not pull away from the welded area. The final density is also typically 1.06g/cm^3. Moulding occurs with steam heating at a pressure of 1 to 1.3 bars for 3 to 9 seconds and then holding for 30 to 60 seconds.

The cycle temperature and time must be closely controlled to achieve the desired quality of products. If temperatures are too low and times short then the beads will have high density; high temperature and/or time period allow too much pentane to escape, and the beads will again have an undesirably high density. Such beads have high density and are smaller than those with low density. A mould filled with the same mass of denser beads will have poor adhesion in the final product, as the beads are too small to develop large areas of surface contact with neighbours, so that weak welds are formed. Inter-granular weld strength depends on surface area, time, temperature, pressure and molecular weight.

4.4 Expandable polystyrene foams (EPS)

EPS is categorised as semi-rigid foam having low density and closed- cells, so it has excellent buoyancy, low thermal conductivity and reasonable water resistance. The EPS product range is very diverse, from eskies to wall insulation to cushioning material for packaging. EPS products are made by moulding and should not be confused with extruded-polystyrene foam (which is used to produce boards for floor/wall/ceiling insulation). Products may be “final” after moulding, or may require secondary processing. Secondary processes include slicing of EPS blocks, or assembly with other materials to make a final product. EPS products that are ready for use after moulding have an integral skin. A thicker (water impermeable) skin can be formed by heating the mould to higher than the steam temperature. EPS products may be sliced from blocks by hot wire cutting or other cutting method. These have no skin. EPS products can be assembled with other materials, by laminating, shrink wrapping, or other suitable joining methods (Deanin1999).

4.5 Comparison of rice cake manufacturing and thermoplastic moulding

Production of rice cakes made with rice cake machines can be compared to the conventional thermoplastic moulding processes described in the preceding section of this chapter. It can be considered to be a two stage compression moulding process. The steeping process is the first stage, when the blowing agent (water) is added and the humidified grains are allowed to equilibrate. Water is able to spread homogeneously within the matrix of starch granules. The puffing process is the second stage, when the grains are heated inside a closed heated mould and foaming occurs after which the mould is opened and the cake removed.

The finished product is similar in structure to moulded EPS. However the process for making rice cakes is somewhat different to that used for EPS and a comparison is tabulated in Table 4.1.

Table 4.1 A comparison of the moulding process for rice cakes and EPS

Process	Rice cake	EPS
Blowing agent	Water (18%)	Water (1%) pentane (6%)
When is blowing agent added	Rice containing 14% moisture is ribbon blended with 4% water	Pentane is added during polymerisation of Polystyrene
Pre-expansion	None	A batch of EPS beads are heated with steam in a vacuum and expanded from 640 to 20 g/L
Ageing	Rice is steeped for 4 hours	Expanded beads are left for 4 to 36 hours to allow air to exchange with pentane
Moulding	Steeped rice is crushed lightly then heated for ~10 s at ~ 230ºC slightly over packed before being removed from the mould	Expanded beads are over packed in the mould, heated with steam for 3–9 s and held for 30 to 60 s before being removed from the mould

Note 1 Rice cake data adopted from Huff, Hsieh and Peng (1992)
2 EPS data adopted from Deanin (1999)

On this basis the understanding of synthetic polymer may help in the investigation of some of the properties of rice for making puffed rice cakes and on the optimisation of quality parameters to understand puffing and adhesion of rice grains.

Chapter 5

Summary of background and description of the project aims

The purpose of this chapter is to summarise the context in which this project has been developed and to describe the aims of the investigation.

5.1 Summary of current situation and significance of the project

Many of the processed foods prepared from cereal grains, including breakfast cereals, are categorised as ready to eat puffed products. Past research studies performed by Hseih et al. (1989, 1992) have demonstrated that during production of puffed rice cakes, higher volume was obtained using lower levels of conditioning (moisture 14%), long tempering time (5hrs), higher temperature (230°C) and a heating time of 8 seconds. Rice cakes made from long grain rice were found to have higher volume at lower moisture level, high heating time and temperature whereas for medium grain rice, higher moisture contents resulted in higher volumes. Puffed rice cakes showed higher volume with increases in time, temperature and moisture level. These researchers did not provide an explanation of why the two types of rice appear to behave differently.

Kim and coworkers (2001), performed studies on the addition of black rice to medium grain brown rice along with increased temperature and time, and their findings were that integrity and robustness of the puffed cakes was increased. The texture of rice cakes modified by the addition of wheat starch has been found to depend more on the foam structure of the rice kernel while the break strength was dependent on the binding between the kernels (Orts et al 2000). A new method to puff cereals, particularly rice cakes, using ultrasound was studied (Capodieci 1999) and the findings emphasised that this form of treatment contributes to the bonding of grains to form a cake that was described as more solid.

Other studies have identified a variety of factors which may influence the puffing of rice and these include the amylose content of the rice along with the surface area, length-width ratio and presence of free water (Rao and Goodman 1984). Chandrasekhar &

Chattopadhyay (1989) performed research on the process of parboiling of paddy and concluded that starch granules were swollen and appeared to be embedded in a protein matrix. Subsequent puffing of the paddy showed various stages of gelatinization of the starch present, the resultant cells within the puffed product varied in the extent of expansion and many void spaces were formed.

In summary, a limited number of studies have addressed the puffing of rice grains and these have not specifically addressed the microstructure of puffed rice cakes or the mechanism of puffing and adhesion. Accordingly this lack of information has formed the basis for the development of the current research project which has sought to elucidate and explain the influence of processing of these increasingly popular products.

5.2 Hypothesis

This research has been based upon the hypothesis that an understanding of the changes that are associated with puffing and adhesion along with the optimisation of process variables may provide a useful basis for reducing breakage during manufacture of rice cakes.

5.3 Project aims

The broad aim of this project has been to investigate the processing of puffed rice cakes. The specific objectives have included:

1. To find the optimum variables for production of rice cakes;
2. To study the microstructure and textural attributes of the product;
3. To examine and compare the quality of cakes made using different processing variables;
4. To develop an understanding of the mechanism of puffing of rice grains and adhesion following the puffing procedure;
5. To evaluate the effect of grain crushing on rice cake quality; and
6. To investigate the influence of morphology of the rice grains on rice cake quality.

Chapter 6

Materials and methods

The purpose of this chapter is to detail the materials and methods used for this study. Included are descriptions of the equipment and methods used. These encompass procedures applied in the laboratory preparation of the rice cakes, those used for cell size measurement, along with other approaches for characterization including the break strength and texture of the rice cakes.

6.1 Materials

Each of the rice samples used in the current study was supplied by SunRice®, Leeton and information about these is presented in Table 6.1.

Table 6.1 Details of the rice grain samples used in the current study

Grain type	Description	Protein content (g per 100g)
Brown rice	Variety Amaroo, grown in crop year 2006, (Sunrice sample sourced directly from production plant)	8.2
White rice	Variety Amaroo, grown in crop year 2006 (Sunrice sample: sourced from production plant)	8.2
Brown waxy rice	Crossbred designation YRW 4, grown crop year 2009 (Sunrice sample number: YRW 4)	7.5
Low protein brown rice	Variety Amaroo , grown crop year 2009 (SunRice sample number: Farm 290-12-0 Tin 16)	7.5
High protein brown rice	Variety Amaroo , grown crop year 2009 (Sunrice sample number: Farm 7514-19-7 Tin 21)	9.3
Reference brown rice	Variety Suncrown , grown crop year 2009 (Sunrice sample number: sourced from production plant)	8.2

6.2 Apparatus and auxiliary equipment

The items of equipment used, together with the details of manufacturers and model numbers are presented in Table 6.2.

Table 6.2 Details and manufacturers of equipment and instrumentation

Equipment	Model	Manufacturer/supplier
Lite energy rice cake machine	Wepop	Real Food Pty Ltd., St. Peters, N.S.W. Australia
ESEM	XL30	Philips, the Netherlands
Minolta chroma meter	CR 300	Minolta Camera Co Ltd, Osaka, Japan
Texture analyser (TA-XT2)	TA-XT2	Stable Microsystems, England
Instron tensile tester	Model no: 4467 Bluehill™ software (Version 1.9, 2004)	Instron, Bayswater, Melbourne, Australia
Oven	Type: UML 500, F No: 891319, NIN 12880-KI	Memmert GmbH, Germany

6.3 Procedure for rice cake production

Rice cakes were made from brown rice, white rice, brown rice with added 1% oil and 1% sugar, brown waxy rice, low protein brown rice and high protein brown rice using Wepop rice cake equipment. A detailed description of this equipment has been presented in Chapter 3, Section 3.1 and a diagrammatic representation is provided in Figure 3.1.

The initial moisture content of all raw rice samples was 13.25±0.5%. The procedure for analysis of moisture is presented in Section 6.4.1. Prior to processing, samples of rice were sprayed with water in the form of a fine mist in a rotary chamber. The amount of water to be added was calculated and added on the basis of the actual sample moisture and that selected for the particular tempering level used in the trials. It is noted that the final and optimum moisture content typically used by SunRice in commercial processing of rice cakes is 18%. In addition, the typical machine settings during the production of rice cakes, basis upon the existing practices of SunRice were: cooking temperature: 260°C; cooking time: 4 seconds; pressure: 0.6 MPa; and size of supply plate: 12.5mm.

In order to evaluate the influence of processing parameters, samples were prepared from different test variables of mould temperature and cooking time, having different tempering moisture levels, as well as rice types, rice varieties and composition as presented in Table 6.3.

Table 6.3 Description of processing variables used in preparation of rice cakes

Test variable	Description of variable values and options evaluated
Mould temperature	248, 258 and 268°C
Heating time	2, 4, 6 seconds
Tempering level	16, 18 and 20% moisture
Formulation variables	1% oil and 1% sugar
Rice type	Medium grain brown rice and white rice
Rice composition	Low protein original thin rice cakes (protein content: 7.5%)
	High protein original thin rice cakes (protein content: 9.3%)
	Low protein original thin rice cakes (waxy brown rice protein content 7.5%)
	Reference samples original thin rice cakes (protein content 8.2%)

6.4 Methods of characterisation of rice and rice cakes

In the analysis of all rice and rice cake samples, replicate sub-samples were analyzed as described for the individual procedure applied. The results of all the test analyses are reported as mean value ± standard deviation. In reporting the data, the latter is abbreviated as s/d.

6.4.1 Moisture determination

The moisture contents of the rice samples and rice cakes were measured following AACC Method 44-15A (1995a) which is an oven drying procedure and sample analysis was carried out in triplicate. This standard method has two variations and the appropriate one was chosen on the basis of the expected moisture of the sample. Those with low values (<13%) were measured using the single stage approach whereas for those of higher moisture (>13%), the two stage procedure was applied.

Empty aluminium moisture dishes with lids were first placed in a pre-heated oven set at 130±1°C. After 1 hour the pans were taken from the oven and cooled in a desiccator containing freshly activated silica gel desiccant for a period of 20 minutes and then weighed. For single stage drying, samples (5.0 g approximately) were accurately weighed into the pre-weighed dishes which were then placed into the oven and dried at 130±1°C. The process of drying, cooling and weighing was repeated after 1 hour until a constant weight was attained. The loss in weight was used to calculate the moisture content of the samples using the following equation:

$$\text{Moisture content (percent)} = \frac{\text{Loss in weight of dish, lid and sample upon drying}}{\text{Initial weight of sample}} \times 100$$

The two stage procedure varied from that described above in the following ways:
The prepared rice sample was initially placed on the top of the pre-heated oven for approximately 14-16 hours to allow the sample to partially dry at a lower temperature. The sample was then re-weighed for moisture loss during air drying, prior to the second stage of drying during which the sample was placed into the oven.

6.4.2 Steeping of rice and moisture determination

Rice (200g) was tempered for 4 hours after calculation and addition of the amount of water required (on the basis of initial moisture content) to bring the moisture level to 18% (or other levels selected for evaluation). During steeping the rice was placed in a sealed container to avoid losses due to evaporation. After 4 hours, the steeped rice was checked for moisture content following the moisture-air-oven two-stage method as described in Section 6.4.1.

Samples of unground steeped rice (5g) were transferred into a Petri dish and this was placed on top of a pre-heated oven for 14-16 hours. The oven temperature was

130±1°C. The sample was allowed to dry in air and then re-weighed. The percentage moisture loss on air-drying was calculated using the following formula:

$$\underset{\text{(percent)}}{\text{Moisture content}} = \frac{\text{Loss in weight of dish, lid and sample upon drying}}{\text{Initial weight of sample}} \times 100$$

The moisture content of the air-dried rice was then determined according to the Moisture-Air-Oven One-Stage method, using grounded rice samples. The total moisture content of the steeped rice was calculated as:

$$\text{Total moisture (\%)} = A + \frac{(100\text{-}A)B}{100}$$

Where

A = % moisture loss on air-drying.

B = % moisture loss on oven-drying.

The moisture content of rice grains and ground rice were calculated on a dry basis. The average s/d was 0.12.

6.5 Determination of physical characteristics

For analysis samples/sub-samples were selected randomly and multiple analyses were carried out as described for the specific analysis procedure. In all cases the results for at least triplicate measurements of individual samples were calculated statistically and are reported as the mean value ± standard deviation. In reporting data, the latter is abbreviated as s/d and the number of replicate determinations is referred to as n.

6.5.1 Measurement of mass and thickness

The mass of the rice cakes was measured on a weighing balance and the thickness of the rice cakes was measured using vernier calipers. The relative standard deviations for these values were generally less than 0.5%. This level of variability relating to mass and thickness are expected and reflect the variability associated with the processing conditions being studied.

6.5.2 Determination of volume and density

The whole rice cake was weighed on a balance and the diameter was measured using vernier calipers at three different points around the circumference of the cake and average values were calculated. The thickness of rice cakes was measured using either film thickness calipers (if the cake was “thin” corresponding to 6 mm or less) or using vernier calipers (if cake was “thick”, greater than 6 mm). Triplicate measurements were taken for each rice cake. The density was calculated using the following:

$$\text{Volume of rice cake (cm}^3\text{)} = V_{Cake} = \pi r^2 h$$

Where:

r = radius of the rice cake
h = thickness of the rice cake

$$\text{Density of rice cake (g per cm}^3\text{)} = \frac{\text{Mass of rice cake}}{V_{Cake}}$$

The typical s/d obtained for these measurements was 10%. This indicates that this variable is reasonably well controlled in production.

6.5.3 Measurement of colour characteristics

The colour of rice cakes was determined using a Minolta Chroma Meter. The instrument was first calibrated using the white calibration tile supplied by the manufacturer. For analysis, the three parameters L^*, a^* and b^* were recorded. The L^* value measures the degree of whiteness/darkness and the higher the L^* value, the lighter the colour. The a^* value indicates the balance between redness and greenness of the sample with positive values corresponding to red colours and negative to green. The b^* value indicates the balance between yellowness (+) and blueness (-). For a^* and b^* readings, values closer to zero indicate less intense colour whereas readings further from zero correspond to more intense chroma characteristics (Hutchings, 1999). Multiple sets of readings (n=10) were taken on all samples by moving the measuring head on a random basis to different locations on the surface of the sample between readings.

6.5.4 ESEM

Samples of rice grains were mounted on circular aluminium stubs with double-sided sticky tape. These were studied by ESEM (Philips XL30) at constant magnification (30×); for each sample many images were taken and stored on computer.

6.6 Determination of textural characteristics

6.6.1 Measurement of puncture break strength

Break strength of rice cakes was measured using an Instron tensile tester (model no: 4467) equipped with the Bluehill™ software (version 1.9, 2004). The test was run in bending mode using a blunt probe. The probe had a hemi-spherical end of diameter 18mm and a load cell of 2 kN was used. The test method adopted for analysis of break strength was developed based on the procedure of ASTM International (method D1667-97) for flexible cellular materials, which is suitable for closed cell foams of low density. The rice cake rests on a horizontal smooth platform over a large hole, 65mm in diameter. In the procedure the probe was lowered into contact with the centre of the top surface of the rice cake. The test was then commenced and the probe descended with a test speed of 5mm/min until breakage of the cake occurred. The deflection and load at break was recorded. Ten replicate determinations were recorded for every sample. The typical relative s/d. values were approximately 30%.

6.6.2 Measurement of texture

Texture analysis testing was conducted using a Texture Analyser (TA-XT2), equipped with the Texture Expert Exceed software package (Stable Micro Systems 1995). Before carrying out the test, the TA-XT2 was calibrated for load using the 50 N (5 kg) load cell and the specific probe chosen for the testing.

For the analysis of samples, both 2 mm and 100 mm compression platens were used in compressive mode at distances up to 6 mm. The set conditions were: pretest speed: 1.0 mm/s; test speed: 5.0mm/s; post- test speed: 10.0mm/s; distance: 50 mm, trigger type: auto; data acquisition rate: 400pps; load cell: 50 kg, probe: 2mm and 100mm compression platen.

Measurement of force was commenced as the probe punctured the rice cake and was recorded as a function of distance as the probe travelled into the rice cake. It was observed that the force increased as the distance travelled by the probe increased, reflecting higher resistance to deformation. The resistance against indentation was calculated up to 2 or 3 mm in depth (33% or 50% of the thickness). Data was collected beyond this depth, but was not considered to be useful as this data was increasingly erratic and each curve was jagged and idiosyncratic. The average s/d. was relatively high (approximately 70%). It is likely that the variability in this test method reflects the structure of the cake and particularly their cellular and brittle characteristics. In puffed products the cells walls are extremely thin and fragile, and the cell size and shape have a non-uniform distribution.

6.7 Measurement of cell size of rice cakes

The measurement of cell size in a rice cake was developed for the purposes of the current study and was based on test methods used to measure the cell size distribution in rigid foams (Lewis and others 1996) and polymeric foams (Sims and Khunniteekool, undated). The methods used for sample preparation and analysis are described in Section 6.8.1. The underlying basis of the approach is briefly described here.

Assuming that all cells are pentagonal dodecahedral, the cell diameter was calculated from an average chord length by using the quantitative stereological equations. The surface area to volume ratio for a dodecahedral cell is given by:

$$S_v = (20.646\, l^2)/(7.663\, l^3) \quad = 2.694/l \qquad (1)$$

$$= 4/c \qquad (2)$$

$$d = 2.671\, l \qquad (3)$$

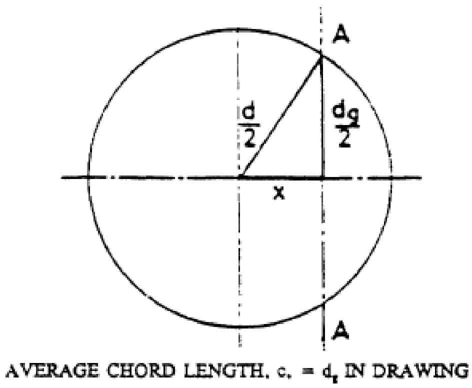
$$S_v = 4/c = (2.57)(2.694)/d \qquad (4)$$

$$d = 1.731\, c \qquad (5)$$

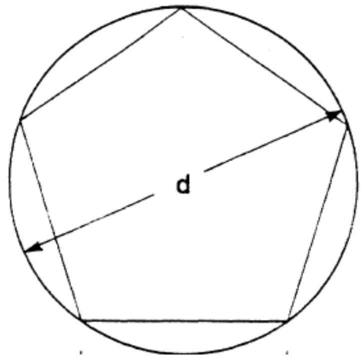
Where:

l	=	length of the chord
d		Diameter of cell
S_v		surface area to volume ratio of a cell

Source Glickman and others (1984,1991)



Measurement of chord length



Cross section of a pentagonal dodecahedron in a sphere *d* (diameter)

Figure 6.1 Diagram showing measurement of chord length and cross section view of pentagonal dodecahedron in a sphere

Note Figure sourced from Lewis and others (1996)

The cell diameter measured on the reference chord length is given by

$d = 1.731\ (n)$

n = counted cell walls observed intersecting reference chord length.

6.7.1 Sample preparation and description of analysis method

Samples were prepared manually by cutting the slices of rice cakes with a surgical blade after immersing the rice cake samples in liquid nitrogen. The purpose of the latter step was to ensure that a clean cutting edge was obtained. The sample prepared was cut through the center of the rice cakes and a small portion of the cut surface (1.5-2.5 mm) of rice cake was taken and mounted onto a circular aluminium stub with double-sided sticky tape. ESEM images were taken and the settings used were: 5.0 Torr, 4°C, 50× magnification, spot size 5.0, accelerating voltage 30 kV and a working distance of approximately 10mm.

The Mocon OX- TRAN Model 2/21 image analyzer was used in conjunction with ESEM. The magnification and focus was adjusted to give a clear image with a suitable number of cell faces (5 to 9 along an average chord length). Cells were counted along each chord line length. Micrographs was examined and categorized as either homogeneous or heterogeneous in cell size distribution on the basis of visual inspection. Each micrograph was then analyzed by obtaining data from at least 5 reference chord line lengths. A typical micrograph of a rice cake sample is presented in Figure 6.1 and this shows the five lines which were inserted onto the image using the software. For each of the lines, the number of cell walls, intersected by the line, was assessed visually and the number recorded.

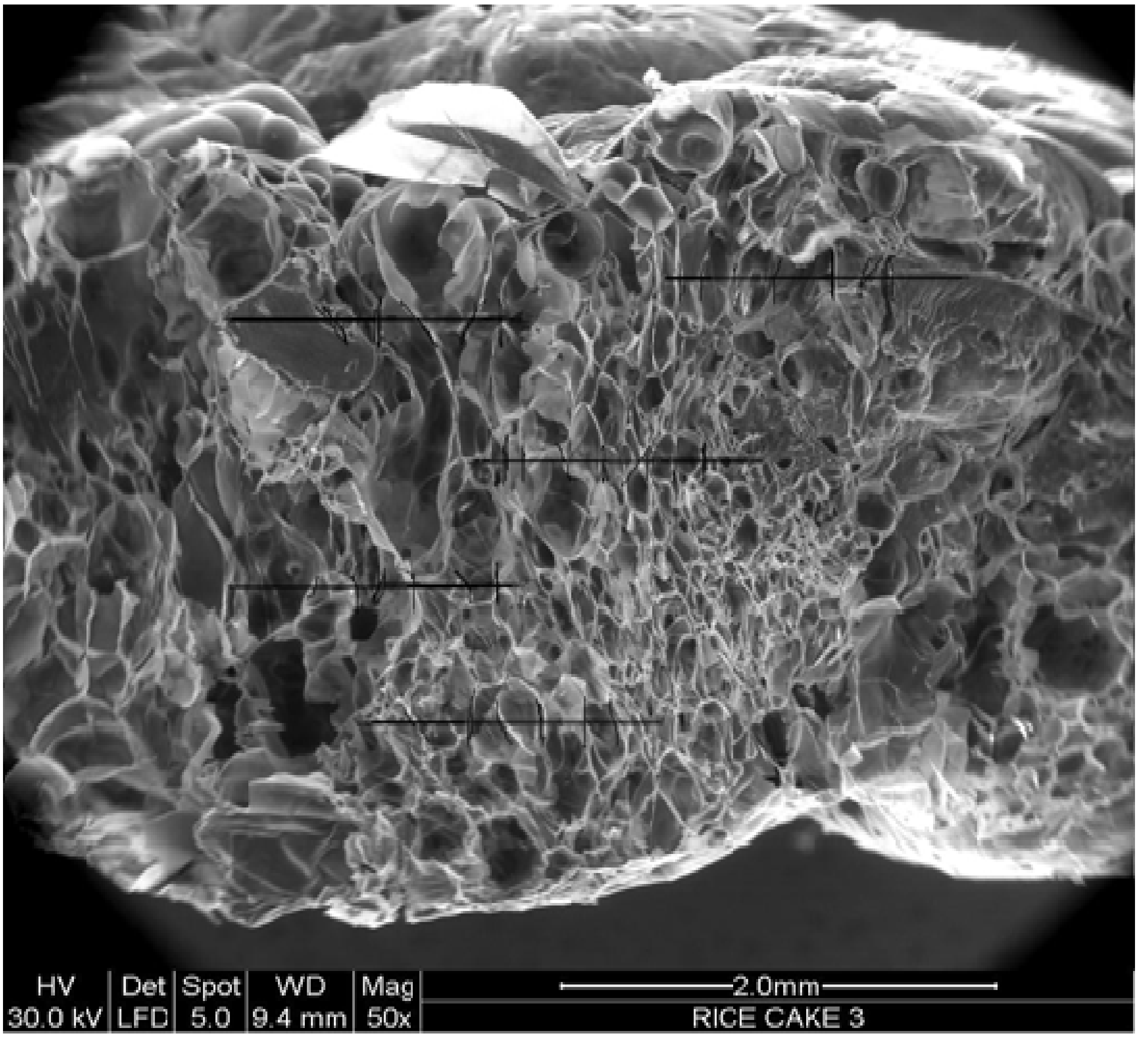


Figure 6.2 Example of a micrograph showing the lines used in the measurement of cell size in a rice cake sample

Chapter 7

Results and discussion: The effect of process parameters on quality of rice cakes

The purpose of this chapter is to discuss the results obtained when rice cakes were prepared on a laboratory scale using a series of different processing variables. An evaluation of the physical and structural properties of mass, thickness and volume as well as break strength of rice cakes is included. This chapter also focuses on the effect of pressure and cycle time on product characteristics.

7.1 Introduction

The physical and structural properties of rice cakes are important quality attributes for packaging operations and consumer acceptability. Past studies have focussed on rice cake production using long-grain and medium grain BR and the influence of tempering and heating conditions (Huff, Hsieh Marek and Peng, 1989, 1992). In the application of the typical process and equipment, the production of rice cakes can be considered to include two main aspects: these are the puffing as well as the adhesion of the rice grains when these are subjected to heat and pressure. During puffing, rice kernels increase in volume several fold and the integrity of the resultant cakes depends on the adhesion of the puffed grains to each other. The puffing relates to volume and adhesion can be assessed through the measurement of break strength. In current commercial practice BR is used as the primary ingredient, however, in order to further enhance our understanding of the factors influencing product characteristics, both BR and WR have been used in the trials reported here.

7.2 Manufacture of rice cakes

In selecting the parameters to be studied here, consideration was given to those used in the few previous studies published on rice cakes as well as current commercial practice. The latter was specifically gained from Ricegrowers in Leeton, NSW, and the trials were carried out using the facilities within their operations. Accordingly the range of settings that could be trialled was limited to those that could be set up using the experimental rice cake units available. It is noted that some of these differed from those used in previously published research. In the current study, the rice cakes were produced using these variables:

1) Tempering moisture levels of 16, 18 and 20%;
2) Heating temperatures of 248, 258 and 268°C;
3) Heating times of 2, 4 and 6 seconds;
4) Mould pressures of 500-580kPa; and
5) Cycle times of 5.8 to 7 seconds.

7.3 Control samples

Control samples of rice cakes were made during each of the three trials using a set of particular processing conditions and these were selected as 18% moisture; mould temperature 258°C; pressure ~580 kPa, heating time 4 seconds (Table 7.1). Control samples were collected at the start and finish of every batch of rice cakes made at different processing variables. The two control samples taken at the commencement and end of a batch enabled an assessment of consistency and repeatability of the cakes to ensure that the condition were under control. The results of the measurements taken for each of the control samples made at the various stages during the project are presented in Table 7.1.

An average standard deviation was calculated to include the data for each of the control samples for all three of the trials and the values found were ±3% for volume and ±10% for break strength (expressed as percentage value with respect to the mean figures in each case). These data represent the level of repeatability achieved across all of the trials and the values indicate good precision. In terms of the validity of the results from the trials, the repeatability values demonstrate that the various parameters being evaluated were adequately controlled for the purposes of the current study.

7.4 Effects of mould temperature

This section details the results obtained when mould temperature was varied and the effects on physical properties of rice cakes.

Table 7.1 Results of analyses of all control samples of rice cakes

Sample no	Mould temp (°C)	Heating time (sec)	Thickness (mm)	Volume (cm^3)	Break strength (N)
First trial					
1	258	4	5.8	45.0	9.2
11	258	4	5.6	42.8	7.5
s/d			0.14	1.5	1.2
Second trial					
1	258	4	5.8	45.1	9.2
22	258	4	5.6	42.3	7.6
s/d			0.2	1.9	1.1
Third trial					
1	258	4	6.5	50.1	11.0
6	258	4	6.4	49.3	11.1
s/d			0.07	0.5	0.07
Av. s/d			0.1	1.3	0.8

7.4.1 Rice cakes made from BR at 16% tempering level

A series of samples of rice cakes were prepared from BR whilst the tempering moisture was held constant at 16%. The thickness and volume of rice cakes were measured and the results are presented in Table 7.2. Both of these were found to increase as higher mould temperatures were utilised whereas the values of break strength did not differ with increased mould temperature.

Table 7.2 The effect of mould temperature on rice cakes made from BR at 16% tempering

Sample no	Mould temp (°C)	Cake thickness (mm)	Volume (cm^3)	Break strength (N)
5	248	4.9	37.9	6.3
2	258	5.6	38.0	6.7
6	268	6.6	50.8	7.1

7.4.2 Rice cakes made from BR at 18% tempering level

For rice cakes made from BR at 18% moisture (Table 7.3) increases in the responses were observed with mould temperature indicating that the higher temperatures provide enhanced puffing of rice cakes. The results also confirm that there was no corresponding change in break strength of rice cakes.

Table 7.3 The influence of mould temperature on rice cakes made from BR at 18% tempering

Sample no	Mould temp (°C)	Cake thickness (mm)	Volume (cm^3)	Break strength (N)
4	248	5.5	42.7	10.3
6	258	6.4	49.3	11.1
5	268	6.6	50.8	10.7

7.4.3 Rice cakes made from BR at 20% tempering level

At the 20% moisture level (Table 7.4) a similar effect on volume occurred as mould temperature was increased. Consistent with the trends seen at the lower tempering levels, there was no clear trend in break strength values at higher mould temperatures.

Table 7.4 Effect of mould temperature on characteristics of rice cakes made from BR at 20% tempering

Sample no	Mould temp (°C)	Cake thickness (mm)	Volume (cm^3)	Break strength (N)
10	248	4.6	35.9	6.5
7	258	5.4	42.0	6.5
11	268	7.2	55.9	6.2

A further series of trials was then carried out in which a tempering level of 18% was used and the effects of adding oil or sugar to the formulation were compared.

7.4.4 Rice cakes made from BR with addition of 1% oil at 18% tempering

The characteristics of cakes made from BR with 1% added oil (Table 7.5) demonstrated increased height and volume but not break strength as higher mould temperatures were applied. However, there was an overall decrease in the cake thickness, volume as well as break strength when compared with cakes made without added oil at each of the three tempering levels chosen for this study (16, 18 and 20%, Tables 7.2 to 7.4). The effect of oil on rice cakes is further discussed later in this chapter.

Table 7.5 Effect of mould temperature on cakes made from BR with addition of 1% oil at 18% tempering

Sample no	Mould temp (°C)	Cake thickness (mm)	Volume (cm^3)	Break strength (N)
18	248	4.2	32.6	5.7
17	258	5.2	39.7	5.1
21	268	5.6	42.6	5.2

7.4.5 The effect of sugar addition on cakes made from BR at 18% tempering

The thickness and volume of cakes made from BR with 1% sugar added at 18% (Table 7.6) were seen to increase with mould temperature and there was relatively little effect of temperature on break strength.

Table 7.6 Effect of mould temperature on cakes made from BR with 1% sugar at 18% tempering

Sample no.	Mould temp (°C)	Cake thickness (mm)	Volume (cm^3)	Break strength (N)
9	248	5.3	40.8	10.3
10	258	6.2	48.0	10.1
11	268	6.6	50.8	9.8

7.4.6 Rice cakes made from WR at 18% tempering level

The preceding trials all involved samples of BR as the primary ingredient, which reflects the approach taken in previously published research as well as in current commercial practice. In order to facilitate direct comparisons and establish the influence of using WR, set of experiments were designed in which this was evaluated and the results are presented in Table 7.7. For these samples, the thickness and volume of the resultant cakes also increased with mould temperature although no influence on break strength was observed.

Table 7.7 Effect of mould temperature on cakes made from WR at 18% tempering

Sample no	Mould temp (°C)	Cake thickness (mm)	Volume (cm^3)	Break strength (N)
15	248	5.1	39.3	9.9
12	258	6.7	50.8	9.9
16	268	7.4	55.8	10.3

The results of WR cakes also showed an increase in the cake thickness, volume as the mould temperature is increased and is consistent with the cakes made from BR at 18% tempering as presented in Table 7.3. The data on break strength of WR showed similarities to that of control samples at 18% tempering BR though the increase was not significant as the mould temperature increased (Table 7.3 and 7.7). Past literature has focussed only on BR (medium and long grain) and no studies have been done to support the current findings.

7.5 Summary of the trials studying effects of mould temperature on rice cake characteristics

The data obtained from the series of trials in which mould temperature was varied are summarised in Table 7.8, and these consistently showed that thickness and volume increased while the break strength was not altered by this parameter.

All of the results obtained during the trials for varying mould temperature were plotted onto a single graph and this is shown in Figure 7.1. As expected, the overall trend is that volume increases with increasing mould temperature. In addition, when only the data for cakes prepared from BR were plotted, the slope of the line of best fit showed a lower slope and a much less obvious trend (Figure 7.2).

Table 7.8 Summary of the effects of mould temperature on physical and structural properties of rice cakes

Rice type/ tempering level	Thickness (mm)	Volume (cm^3)	Break strength (N)
BR 18% (control)	Increases	Increases	No significant trend
BR 16%	Increases	Increases	No significant trend
BR 20%	Increases	Increases	No significant trend
BR 18%+1% oil	Increases	Increases	No significant trend
BR 18% + 1% sugar	Increases	Increases	No significant trend
WR 18%	Increases	Increases	No significant trend

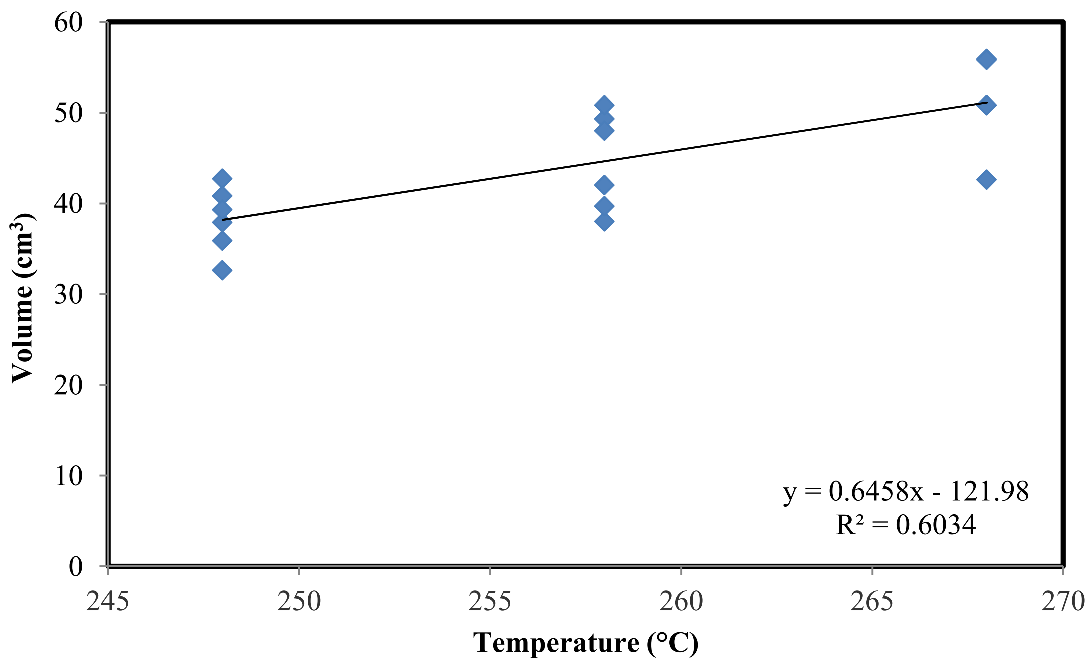


Figure 7.1 Overview of the volume of rice cakes made at different mould temperatures
Note: Data has been included for all treatments for which mould temperature was varied

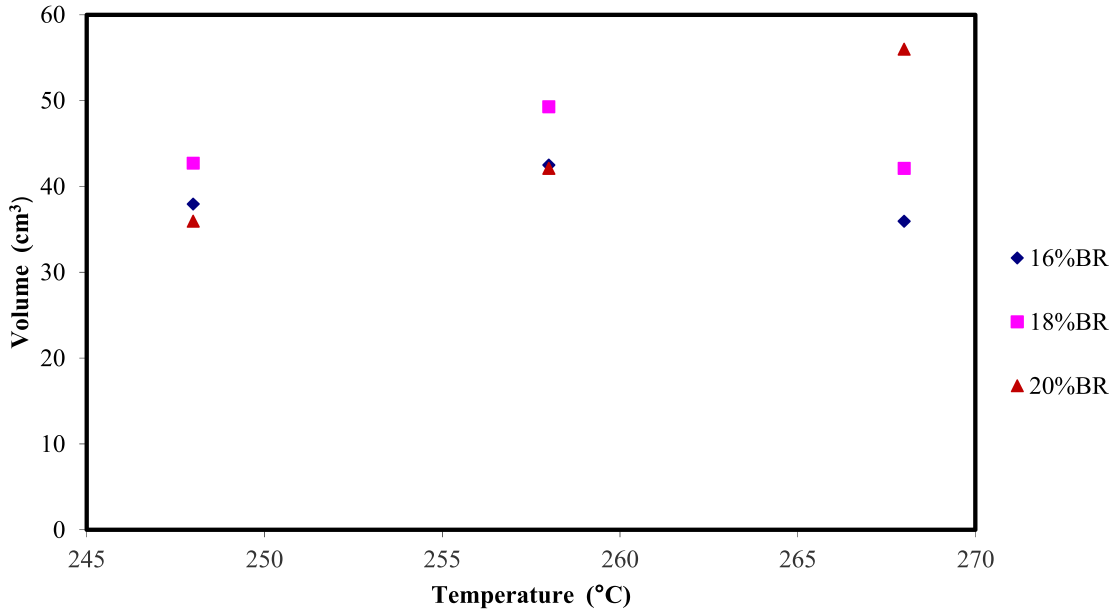


Figure 7.2 Volume of rice cakes made from BR with different mould temperature (248, 258, 268°C) at 16,18 and 20% tempering

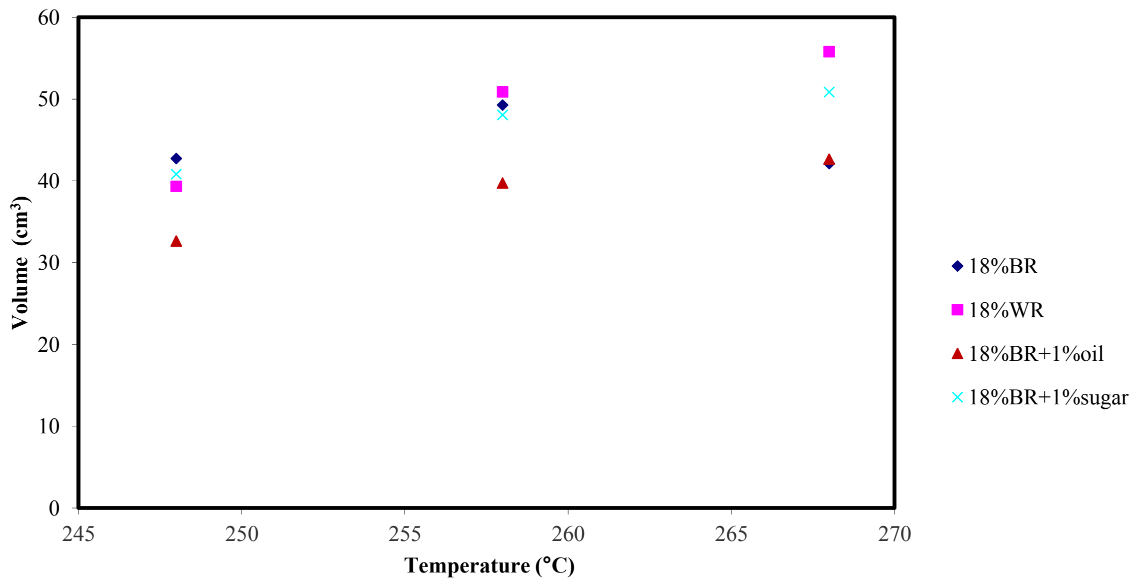


Figure 7.3 Volume of rice cakes made for samples at 18% tempering at different mould temperature (248, 258, and 268°C)

7.6 Discussion on the effect of mould temperature on cake properties

The volume increased with higher mould temperature across a wide range of moisture contents of 16 to 20%. The same increasing trend was observed in cakes made with WR, BR with added 1% oil and sugar.

Hsieh and others (1989, 1992) observed a similar increase in volume of rice cakes with increasing temperature from 200 to 230°C for long grain rice. Another study carried out on wheat cakes showed that specific volume increased with increases in moisture content, tempering time, heating temperature and time (Fan, Hsieh & Huff 1999). However the past studies have not been focussed on elaborating the mechanism of puffing in rice or cereal cakes.

The other area of study on polystyrene foams gave an insight that increasing temperature led to higher volume as more gas diffuses into the cell and expansion continues for longer. Higher temperature also gives more expansion as it creates a higher saturation pressure. In polystyrene foam the foaming temperature controls the impact strength. Too high temperature can destroy the cell distribution lowering the strength of the foam (Doroudiani and Kortschot 2003). A comparison with the knowledge of foaming in synthetic foams suggests the following mechanism of puffing in rice cakes.

The increases in the temperature inside the mould could accelerate water evaporation and melting of rice starch. The higher temperature lowers the viscosity facilitating the expansion of each cell. The temperature of the starch decreases rapidly as each cell expands due to the latent heat of vaporisation. Hence the viscosity of the starch increases rapidly during expansion which stabilizes the foam structure until the pressure exerted by evaporation is in equilibrium with the elastic forces in the visco-elastic starch, when expansion ceases. Hence the volume of rice cake increases with increasing temperature.

In addition, the current study on rice cakes has demonstrated that there was no significant trend in the break strength of rice cakes during the first trial and subsequent trials with different processing and composition variables as the mould temperature is increased across a wide range of moisture contents.

In the past studies, Hsieh and workers (1999) suggested that water affects the texture of wheat cakes and found higher volume, greater surface area and higher adhesion strength. Their results also indicated that hardness of wheat cakes decreased as moisture content and tempering time increased and increased as heating temperature and time increased. Subsequently Orts and co-workers (2000) reported upon the effect of wheat starch on textural properties of rice cakes.

There is no literature on break strength in rice cakes. A comparison with synthetic polymer foams suggests that two main factors affect the cake strength: the mechanical strength of adhesion between the surface of rice grain and mechanical strength of individual puffed rice grains. Break strength of the cake is determined by the weaker of the two factors.

7.7 Effects of heating time

This section details the effect of heating time on the physical properties of rice cakes prepared using the control and a series of other processing parameters.

7.7.1 Rice cakes made from BR at 16% tempering moisture

The thickness and volume of rice cakes made from BR at 16% moisture (Table 7.9) was found to increase with increases in heating time and break strength did not show clear differences when the heating time was increased.

Table 7.9 Effect of heating time on rice cakes made from BR at 16% tempering

Sample no.	Heating time (sec)	Cake thickness (mm)	Volume (cm^3)	Break strength (N)
3	2	4.9	38.0	6.1
2	4	5.6	42.4	6.6
4	6	5.9	45.6	7.6

7.7.2 Rice cakes made from BR at 18% tempering

The thickness and volume of rice cakes made from BR at 18% (Table 7.10) increases with increase with heating time and also the results also showed that there was no significant change in the break strength of the rice cakes.

Table 7.10 Effect of heating time on cakes made from BR at 18% tempering

Sample no.	Heating time (sec)	Cake thickness (mm)	Volume (cm^3)	Break strength (N)
2	2	5.1	39.43	9.1
1	4	6.5	50.12	11.0
3	6	6.8	51.83	10.0

7.7.3 Rice cakes made from BR at 20% tempering

The thickness and volume of rice cakes made from BR at 20% (Table 7.11) showed that for 4 and 6 seconds, the results follow a trend of increasing thickness and volume .The break strength shows no obvious effect with the increase in the heating time. This is similar to the trends seen with increases in heating time at 16% and 18% moisture (Tables 9 & 10).

Table 7.11 Effect of heating time on rice cakes made from BR at 20% tempering

Sample no.	Heating time (sec)	Cake thickness (mm)	Volume (cm^3)	Break strength (N)
8	2	6.6	51.4	7.1
7	4	5.4	42.1	6.5
9	6	7.1	54.5	6.9

7.7.4 Rice cakes made from BR with addition of 1% oil at 18% tempering

The thickness and volume of rice cakes made from BR with added 1% oil at 18% (Table 7.12) increases with higher heating time. The break strength shows no strong trend with the increase in the heating time. There is an overall decrease in the cake thickness, volume and break strength when compared with cakes made with BR at 16%, 18%, and

20% moisture and the results were similar to those obtained when temperature was varied (Tables 7.2, 7.3 and 7.4) of mould temperature.

Table 7.12 Effect of heating time on rice cakes made from BR with addition of 1% oil at 18% tempering

Sample no.	Heating time (sec)	Cake thickness (mm)	Volume (cm^3)	Break strength (N)
19	2	4.3	33.1	4.5
17	4	5.2	39.7	5.1
20	6	5.2	40.1	4.3

7.7.5 Rice cakes made from BR with added 1% sugar at 18% tempering

The thickness and volume of rice cakes made from BR with added 1% sugar at 18% (Table 7.13) increased with increased heating time. The break strength shows no corresponding effect of heating time.

Table 7.13 Effect of heating time on cakes made from BR with 1% sugar at 18% tempering

Sample no.	Heating time (sec)	Cake thickness (mm)	Volume (cm^3)	Break strength (N)
7	2	5.1	39.6	8.8
10	4	5.3	40.8	10.3
8	6	6.7	52.2	9.7

7.7.6 Rice cakes made from WR at 18% tempering

The thickness and volume of rice cakes made from WR at 18% (Table 7.14) increased with higher heating time. The break strength showed no significant trend with higher heating time and is similar to the trends seen in other samples made from BR at 18% moisture content. The results of the effect of heating time on WR are consistent with that of mould temperature as discussed in Section 7.4.6.

Table 7.14 Effect of heating time on rice cakes made from WR at 18% moisture

Sample no.	Heating time (sec)	Cake thickness (mm)	Volume (cm^3)	Break strength (N)
13	2	5.1	38.7	9.1
12	4	6.7	50.8	9.9
14	6	7.2	55.4	10.2

7.8 Summary of effect of heating time on physical and structural properties of rice cakes

The results (Table 7.15) obtained from the series of trials in which heating time was varied consistently (2, 4, & 6 sec) showed that the thickness and volume increased whereas break strength was not changed by this parameter. The results were similar to the results of mould temperature (Table 7.8).

Table 7.15 Summary of the influence of heating time on physical and structural properties of rice cakes

Rice type/ moisture content	Thickness (mm)	Volume (cm^3)	Break strength (N)
BR 18% (control)	Increases	Increases	No significant trend
BR 16%	Increases	Increases	No significant trend
BR 20%	Increases	Increases	No significant trend
BR 18%+1% oil	Increases	Increases	No significant trend
BR 18% + 1% sugar	Increases	Increases	No significant trend
WR 18%	Increases	Increases	No significant trend

7.9 Graphical representations of effect of heating time on volume of rice cakes

7.9.1 Effect of heating time on volume of rice cakes made from BR at 16%, 18% and 20% tempering, BR with added 1% sugar and oil and WR at 18% tempering

The volume data of rice cakes made at different heating time showed that volume increases with increase of heating time (Figure 7.4).The value of R – square (0.3851) indicates that there is a slight trend of increasing volume as the heating time is increased.

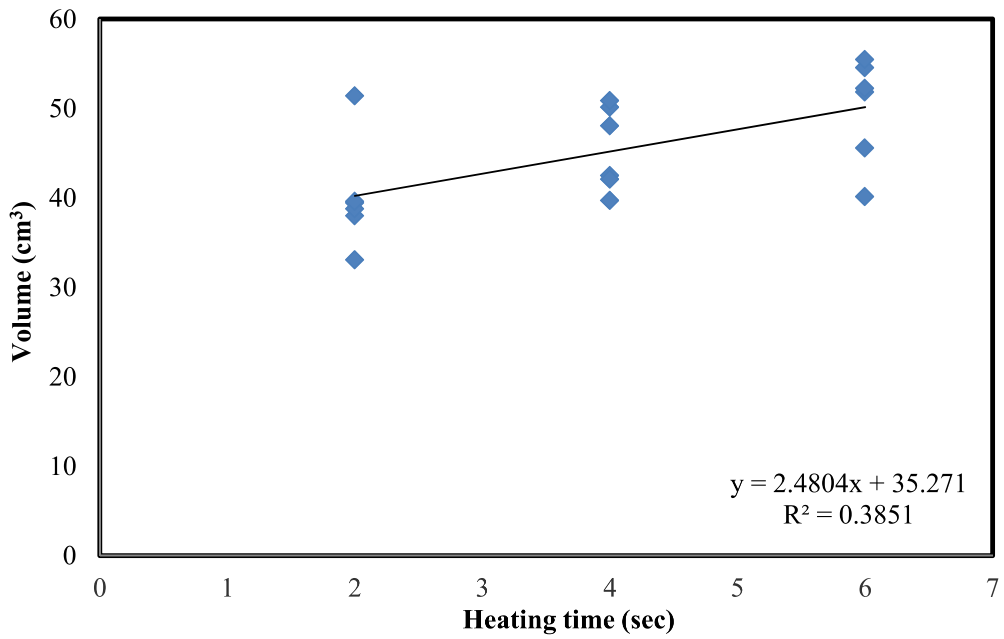


Figure 7.4 Overview of the volume of rice cakes made with different heating times
Note: Data has been included for all the treatment for which heating time was varied

7.9.2 Effect of heating time on volume of rice cakes made from BR at 16, 18 and 20% tempering

An overview of the volume of the cakes (Figure 7.5) confirms that there is an increase as the heating time and tempering level increases. The results are similar to those observed for mould temperature (Figure 7.1)

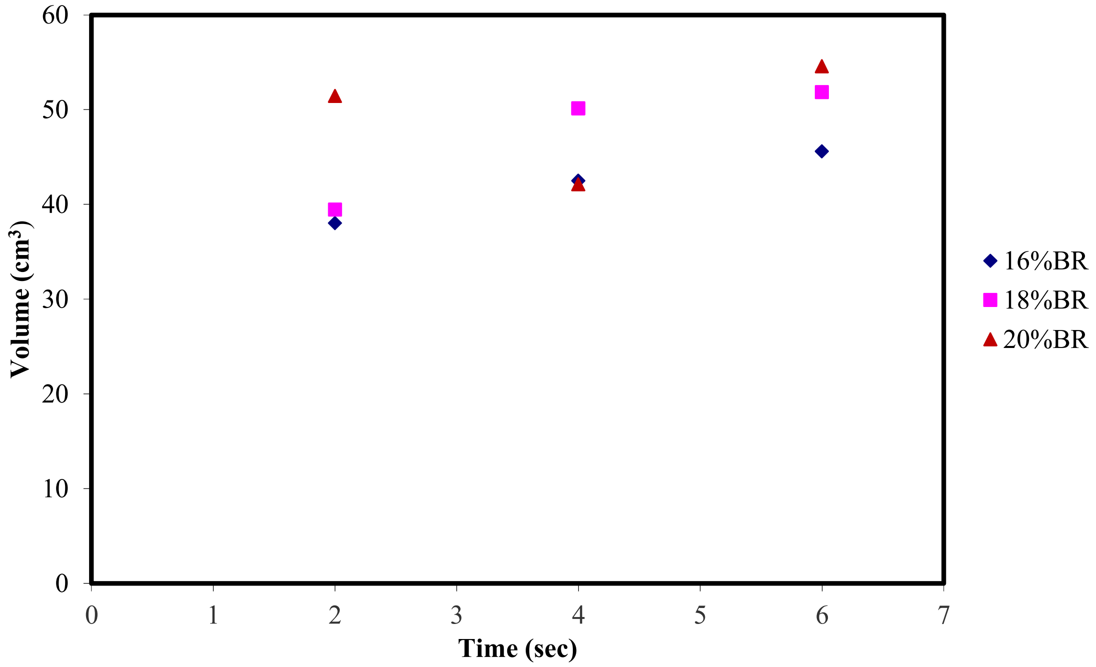


Figure 7.5 Volume of rice cakes made from BR with different heating times (2, 4, 6 sec) at 16, 18, 20% tempering

7.9.3 Effect of heating time on volume of rice cakes made from BR, WR, and BR with added 1% oil or sugar at 18% tempering

The data shown in Figure 7.6 provides an overview of the data obtained for volume of the rice cakes made during the various trials for all of the treatments at 18 % tempering moisture. The results are similar to those observed for mould temperature (Figure 7.3).

7.10 Discussion on the effect of heating time on properties of cakes

The thickness and volume increases with increase in heating time and are consistent with the effects of a higher mould temperature, discussed above. In contrast, the break strength showed no clear trend when heating time was increased. Longer heating times were observed to increase the extent to which puffing occurred during processing of the rice cakes. The results on the physical and structural properties of rice cakes for heating time are similar to those for mould temperature. A longer heating time appeared to allow starch to gelatinise to a greater extent which was similar to the effects of a higher mould temperature discussed earlier (Section 7.6). The volume and thickness increased with an increase in heating time and these results are similar to the other studies done on

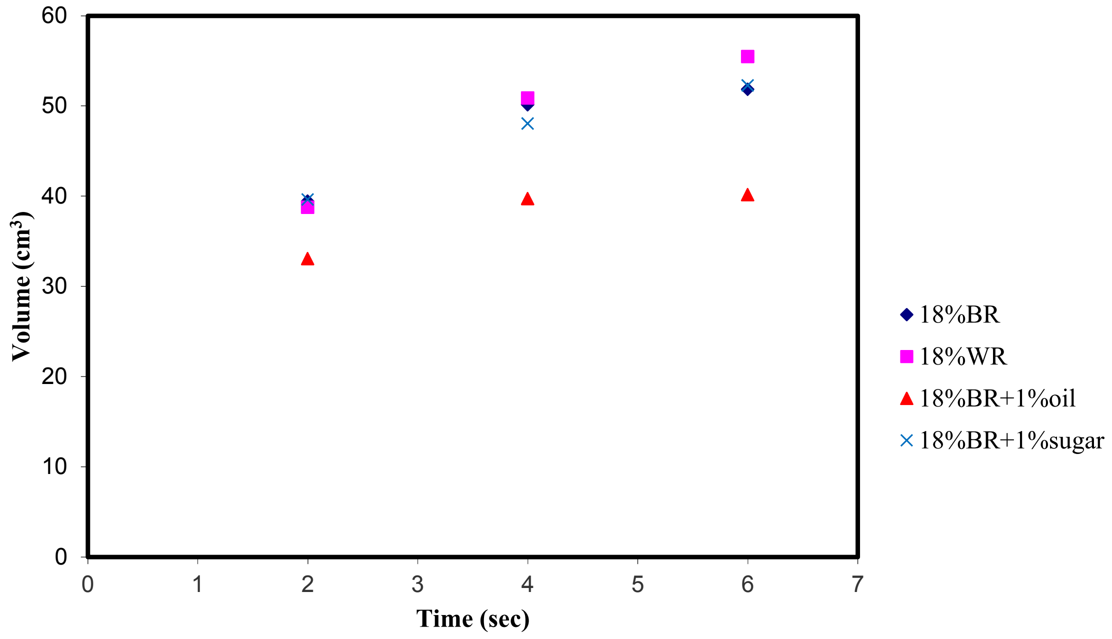


Figure 7.6 Volumes of rice cakes for samples at 18% tempering and having different heating times (2, 4, 6 sec)

rice cakes by Hsieh and co-workers (1989). The effect of heating time on foams suggests that higher heating, as for temperature, facilitates diffusion of more gas from the polymer matrix into cells during expansion.

The results also show similarities with the optimum foaming time in polystyrene foams which depend on saturation pressure as the most important factor in determining the impact strength (Doroudiani and Kortschot 2003). The saturation pressure is not a variable in rice cake manufacture, and therefore the findings for break strength of rice cakes indicate that this is not sensitive to the factors involving heating.

7.11 The effect of pressure during processing of rice cakes

This section describes the effect of pressure and the range of setting for used in this study was from 500 to 580 kPa. This pressure range was used to understand an optimum pressure in uniform puffing of rice cakes. The data on cake thickness, volume and break strength using range of pressure settings is presented in Table 7.16 and Figure 7.7.

Table: 7.16. Effect of equipment pressure during manufacture of rice cake

Sample no.	Mould temp. (°C)	Heating time (min)	Mould pressure (kPa)	Cake thickness (mm)	Cake volume (cm^3)	Break strength (N)
8	258	4	500	5.6	43.1	7.7
9	258	4	540	3.6	27.6	6.6
11	258	4	560	5.6	42.8	7.5
1	258	4	580	5.8	45.0	9.2

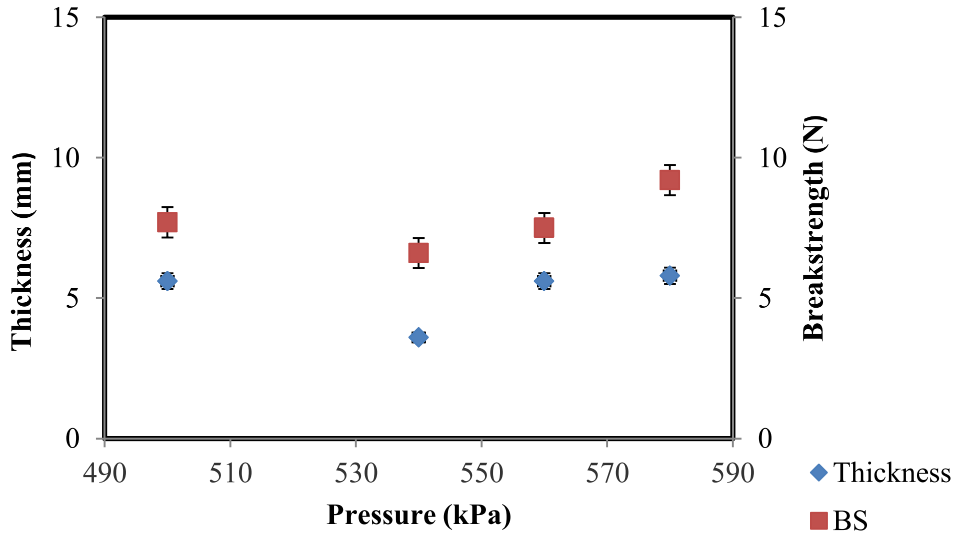


Figure 7.7 Effect of pressure on thickness and break strength of rice cakes at 18% tempering

The results (Table 7.16 and Figure 7.7) showed that there was no obvious difference in the thickness or break strength with changes in pressure. During the process, the pressure applied crushes the grains and increases the surface area of rice grains which is in contact with the hot mould, causing more rapid conduction of heat. The rice grains soften and a viscous paste forms, with expansion to form a puffed rice cake. The studies done by Hsieh & co-workers (1989, 1992 and 1999) did not report on the effect of pressure on rice cake puffing implying that crushing may not have been a part of the process used. Mariotti and others (2006) studied pressure (1.3-1.5MPa) as one of the variables during puffing of grains but provided no discussion of the purpose of the pressure. Studies on EPS foam have demonstrated that saturation pressure was the most important factor controlling foam density (Doroudiani & Kortschot 2003). The saturation pressure is not a variable in the rice cake manufacture, as the moulds have channels to allow the steam to escape. The physical properties including volume and break strength of rice cakes prepared in the experimental trials most closely corresponded with those from commercial production for a pressure of 580kPa and therefore this was used in all later trials of rice cake production.

7.12 Effect of cycle time

The effect of cycle time on cake properties was studied by varying the cycle time from 5.8 to 7.0 sec (Table 7.17 & Figure 7.8). This relatively narrow range of cycle times was dictated by the limits imposed by the equipment used. The cycle time was varied by speed at which the top platen was moved away from the lower platen. If the top platen was moved rapidly the chamber opened rapidly allowing for immediate and maximum expansion of the puffed rice grains. Accordingly, a short cycle time would be expected to produce cakes with a greater extent of puffing and if the top platen were to be moved slowly then the opening of the chamber would result in a more controlled expansion of the product.

Table 7.17 Effect of cycle time on puffing of rice cakes

Sample no	Mould temp (°C)	Heating time (min)	Cycle time (sec)	Cake thickness (mm)	Cake volume (cm^3)	Break strength (N)
8	258	4	5.8	12.2	93.8	10.5
9	258	4	6.0	5.8	45	9.15
11	258	4	6.0	5.6	42.8	7.5
1	258	4	7.0	3.6	27.6	6.6

The effect of cycle time on thickness was relatively large (Table 7.17 & Figure 7.8). The shorter the cycle time, the thicker were the cakes (12.2 mm) in comparison with the controls (5.7 mm) and those for the long cycle time (3.6 mm). For those samples prepared using a cycle time of 5.8 seconds, the upper surface of the cakes did not appear to be flattened - the cakes were “free foaming” and were not constrained by the top platen and reached maximum thickness (12.2mm) and volume (93.8cm^3).

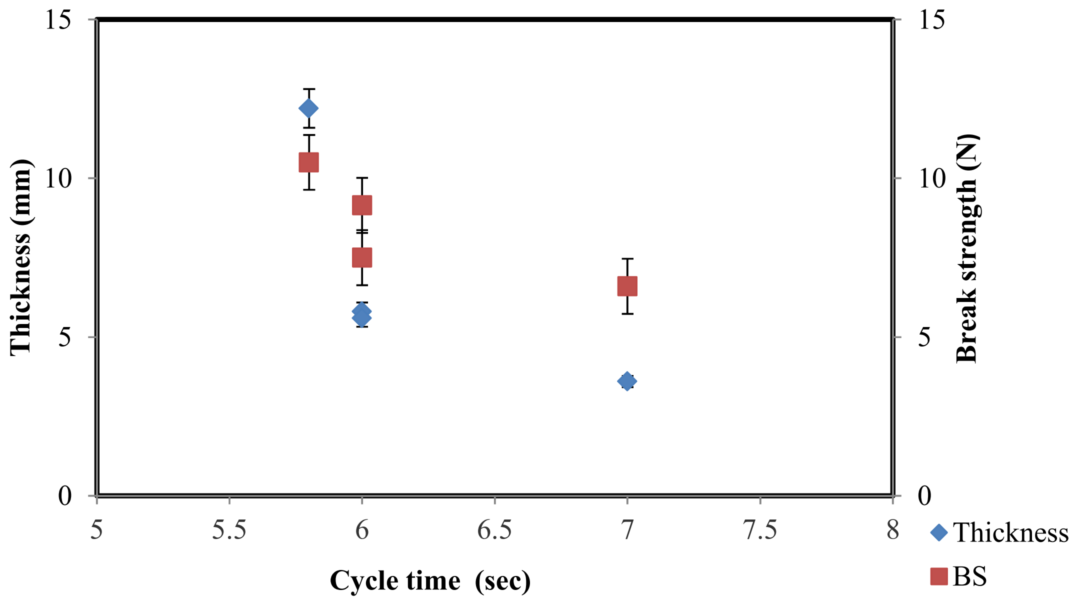


Figure 7.8 Effect of cycle time on thickness and break strength of rice cakes at 18% moisture

A clear effect of cycle time on break strength was observed (Table 7.17 & Figure 7.8). The shorter the cycle time, the higher the break strength and the resultant thickness was greater. This indicates that adhesive bonding between rice grains was stronger at higher volumes. Previous studies on rice cakes or those made from other cereal grains did not consider cycle time as a variable and there is no literature which investigates its effect on puffing or adhesion.

As discussed in Section 7.10, break strength depends upon the inter- and intra- grain strength of the rice, and specifically reflects whichever is the weaker of the two. Inter-grain strength is weaker when the grains are not puffed sufficiently. The strong correlation between thickness, volume and break strength indicates that inter- grain strength was the weaker in these samples.

With a higher extent of puffing, grains are pressed together with more force, so that stronger inter- grain bonds are formed. If rice grains “free foam”, they expand at high rates, and grains are pressed together with more force, forming stronger bonds. This is consistent with the trends observed in the current study with varying time and temperature, although these trends were relatively small. The application of a wide range of temperatures and heating times would be expected to result in a greater change in the volume of cakes and, in addition, from the current study cycle time appeared to have a much greater effect on volume than did varying temperature and heating time.

7.13 Effect of tempering moisture on rice cake production

Based upon previous experience with the processing of cereal grains, particularly puffing, it is expected that the tempering moisture level of the raw rice will be one of the main factors influencing cake characteristics. It is likely to be the critical factor which can affect the properties of the rice cakes in terms of thickness, volume and break strength. The brown rice used to produce cakes was tempered to varying moisture levels (Table 7.18) in order to study the effect of this parameter on cake thickness, volume and robustness.

Table 7.18 Effect on puffing of rice cakes due to tempering moisture level

Moisture content (%)	Cake thickness (mm)	Volume (cm^3)	Break strength (N)
16	5.6	42.5	6.7
18	6.4	49.3	11.70
20	5.5	42.1	6.5

The thickness and volume of brown rice cakes shows no clear overall trend when moisture was increased. In previous reports, Hsieh and co-workers (1989) prepared cakes with moisture contents from varying from 14 to 20% and observed a consistent decrease in volume with increases in moisture for long grain rice whereas Huff and others (1992) found the opposite for medium grain rice. The latter workers commented that the decrease was unexpected but did not provide commentary on the difference between the two studies. It was also stated that “Temperature determined vapour pressure of the moisture and thus the degree of puffing”. The difference between this study and the previous studies may relate to varietal characteristics which typically have a substantial influence on the properties of the resultant food products. The effect of moisture content on thickness and volume of brown rice cakes showed a peak at 18% and the effect on break strength was substantial at 18% moisture as compared to that observed for 16 and 20%.

7.14 Colour analysis of rice cakes

Over recent times colour analysis of samples has evolved from visual analysis to the use of instrumental approaches. One of the more widely used instruments is the Chroma Meter. The evaluation of colour using the most widely adopted approaches consists of the main parameters of L^*, a^* and b^* measured using the Chroma Meter. The L^* value measures the degree of whiteness/darkness and the higher the L^* value, the lighter the colour. The a^* value indicates the balance between redness and greenness of the sample with positive values corresponding to red colours and negative to green. The b^* value indicates the balance between yellowness (+) and blueness (-). For a^* and b^* readings, values closer to zero indicate less intense colour whereas readings further from zero correspond to more intense chroma characteristics (Hutchings 1999).

7.14.1 Effect of temperature on colour

The results measured using the Chroma Meter (Table 7.19) confirm visual observations and the data shows that, as expected, the observed colour became darker with increasing temperature of processing. This corresponds to the lightness value (L^*) increasing with an increase in temperature and the yellowness (Chroma b^*) decreased. As a result the measured colour showed the converse to the observed colour in that the cake becomes paler when assessed in terms of b^* value. The increase in lightness value and decrease in yellowness may be related to the greater expansion of the rice kernels, corresponding to a higher volume. The rice grains are observed to become more transparent as the cell walls become thinner. Huff and others (1989, 1992) reported that rice cakes with lower specific volume were lighter and whiter colour. The expansion of rice creates numerous tiny air cells within each kernel and the resultant material is porous. It is expected that this will contribute to higher values of L^*. In addition it is predicted that the larger is a cell in the rice cake product, the thinner will be the wall.

Table 7.19 *L, *a**, and *b** values of rice cakes made at different mould temperatures**

Sample no	Temp (°C)	Volume (cm^3)	Visual observation	Lightness (*L**)	Hue (*a**)	Chroma (*b**)
7	248	41.0	light	77.4±0.02	1.9±0.04	12.3±0.01
1	258	45.0	yellow	75.6±0.02	2.4±0.01	12.7±0.02
6	268	48.2	dark	88.6±0.01	1.5±0.01	4.6±0.01

Note Results are presented as mean ± sd of five readings

7.14.2 Effect of heating time

The effect of heating time on rice cake colour is that cake lightness $L*$ decreased and the yellowness $b*$ and redness $a*$ increased with heating time. This is consistent with the visual observations of colour which changed from pale to dark. In previous reports, the effect of heating time on colour of rice cakes showed a decrease in lightness with an increase in redness and yellowness (Huff and others 1992). However, this contrasts and appears inconsistent with the trends obtained in the current study and discussed above.

The results obtained here and the decrease in the cake lightness with extended heating time can be attributed to the increase in volume which makes rice cakes more transparent. The value of lightness ($L*$) is increased with increases in mould temperature and this is attributed to increased browning at the cake surface.

Table 7.20 *L, *a**, and *b** values of rice cakes made at different heating time**

Sample no	Heating time (sec)	Volume (cm^3)	Visual observation	Lightness (L*)	Hue (a*)	Chroma (b*)
7	2	32.3	Light	95.10±0.02	0.52±0.02	2.9±0.01
1	4	42.8	Normal	75.72±0.04	0.67±0.01	13.0±0.01
6	6	49.4	Dark	70.58±0.02	3.58±0.01	14.4±0.01

Note Results are presented as mean ± sd of five readings

7.15 General discussion and summary of processing variables on properties of rice cakes

A survey of the scientific literature shows that very few studies have been done on rice cakes. In addition, there has been no focus on measuring the effect of processing variables (moisture content, temperature and heating time) on the physical properties of rice cakes (volume, density and colour). The effect of wheat starch on robustness of cakes had been studied for those made using BR and the effect of moisture and additional ingredients (salt, shortening and sucrose) on volume and texture was evaluated. These previous studies found that the volume increased when moisture level increased, and might either increase or decrease when temperature and cooking time were increased, and may also be dependent on rice variety. The cake robustness was enhanced when wheat starch was added.

The results in this current study on physical and structural properties of rice cakes made using different processing variables for BR showed that cake volume increased with higher mould temperature across a range of moisture contents. The same increasing trend was seen in cakes made from WR, as well as for BR with added oil or sugar. The volume results were consistent with the studies by Hsieh and others (1992). There is no literature on the study of WR for puffed products.

The results on break strength of rice cakes did not show any clear difference with different processing and compositional variables as the mould temperature was increased across a range of moisture contents. Break strength of rice cakes made with added oil was significantly lower than that found for rice cakes made with either WR or BR with sugar. There is no literature on break strength in the rice cakes but in one study cake texture was found to show greater flexibility and fracture strength as a result of addition of wheat starch (Orts 2000). The results of the effect of heating time on physical and structural properties are quite similar to those found with mould temperature. There was no significant trend in break strength when the heating time was increased.

In the context of the current studies, the following mechanism of puffing in rice cakes is proposed. Firstly, the tempered rice grains are heated in the hot mould. The water present within the grain and including that has been taken up during tempering starts to heat and the effect is the formation of a viscous molten paste. As heat is transferred from the mould into this liquid material, some of the water starts to evaporate and as a result there is a formation of small cells of gas within the viscous starch paste. These cells form as very small bubbles and as more water evaporates the steam diffuses into the cells which start to expand. Associated with the evaporative process, as each cell expands the temperature of the adjacent starch solution decreases rapidly due to the latent heat of vaporisation. As a consequence, the viscosity of the starch material increases during this expansion. The pressure exerted by evaporation increases until it is in equilibrium with the elastic forces in the visco-elastic starch matrix, at which point expansion ceases and the foam structure becomes stabilised.

In the context of this model of the processes occurring within the cake during processing, higher mould temperatures are expected to correspond with slower cooling and lower viscosity for longer times so that the total volume of the rice cake increases with increasing temperature.

The results for the effect of pressure on the thickness or break strength on rice cakes showed little effect. Pressure crushes the grains as well as increasing rice grain surface contact with the hot mould, causing more rapid conduction of heat. The rice grains soften, so that the starch matrix expands to form a puffed rice cake. The effect of pressure on rice cake puffing has been not reported in the past literature and whether pressure contributes to puffing or adhesion remains clear at this stage.

The change of cycle time changed cake thickness significantly and the effect of cycle time on break strength was similar to thickness. The thicker is the cake, the higher the volume and break strength. This indicates that the adhesive bonds between rice grains were stronger at higher volumes. Previous studies on rice or other cereal cakes did not consider cycle time as a variable. In addition we are unaware of any literature which investigates its effect on puffing or adhesion.

The effect of moisture content on thickness and volume of BR cakes showed a peak at 18% moisture. These results differ from those reported in the literature where volume decreased and increased with moisture in medium grain rice (Huff and others 1992). These differences in the effect of moisture may be due to the characteristic of the particular rice varieties. The break strength was significantly higher at 18% moisture. The samples with added sugar at 18% moisture had similar break strength to the control sample and also WR at 18% moisture.

The results on break strength of rice cakes form the basis for a proposed mechanism of adhesion: two main factors affect the cake strength; the mechanical strength of adhesion between the surfaces of neighbouring puffed rice grains, and the mechanical strength of individual puffed rice grains. Break strength of the cake appears to be determined by whichever is the weaker of these two factors.

Chapter 8

Results and discussion: textural properties of rice cakes

The purpose of this chapter is to present and discuss the results obtained during the evaluation of texture of rice cakes made using different processing and compositional variables.

8.1 Introduction

Texture is a critical quality parameter in puffed cereals and snack foods (Bourne 2002). Many snack foods have cellular structures which are easier to bite and chew and the cells consist of gas within a solid envelope. For example, puffed rice products are cellular solids with low density and are considered to be typical polymeric foams (Gibson and Ashby 1988). An important textural attribute of puffed cereals is brittleness and this is reflected in the appeal of products which are crisp and crunchy. A variety of different terms is used in the scientific literature to denote the texture of foods and among these are stiffness, robustness, integrity, break strength and toughness. In this chapter, the term stiffness has been adopted to represent the textural measurements of the rice cakes. The objectives of this phase of the current study have been to:

1. Investigate the deformation and fracture of rice cakes during compression; and
2. Propose a mechanism of fracture of puffed rice cakes.

8.2 Experimental design and test procedure

Samples of rice cakes were taken to represent those prepared using a series of formulations: BR, WR and BR with 1% of either oil or sugar, at different levels of tempering, as well as various mould temperatures and heating times. The process variables and experimental design are presented in Tables 8.1 and 8.2.

The texture analysis testing was conducted using a Texture Analyser (TAXT2), equipped with a 50 N (5 kg) load cell. The force was measured as a cylindrical probe indented the rice cake and was recorded as a function of the distance the probe travelled into the rice cake. In this system, the indentation increases with force and a steeper initial slope reflects higher resistance to deformation which is interpreted as "stiffness" in puffed rice cakes. In reporting the results obtained in this study, graphs are generally presented to show force plotted against distance corresponding to 1 mm in penetration of the probe, noting that the total thickness of samples was 6 mm reflecting the constraints imposed by the mould during cake processing. The slope on the force-distance curve was calculated using the slope function within Microsoft Excel software. In some cases, a standard deviation value is presented for samples and this was calculated for one specific mid-range point during indentation to facilitate comparison.

Table 8.1 Experimental design used in production of rice cakes for various test and compositional variables (BR, WR, BR + 1% oil and tempering moistures of 16, 18, and 20%)

Sample details	Tempering moisture (%)	Cooking time (sec)	Temperature (°C)
BR			
0 (Production)	17	4	260
1 (Control)	18	4	258
2	16	4	258
3	16	2	258
4	16	6	258
5	16	4	248
6	16	4	268
7	20	4	258
8	20	2	258
9	20	6	258
10	20	4	248
11	20	4	268
22 (Control)	18	4	258
WR			
12	18	4	258
13	18	2	258
14	18	6	258
15	18	4	248
16	18	4	268
BR +1% oil			
17	18	4	258
18	18	4	248
19	18	2	258
20	18	4	258
21	18	6	268

Table 8.2 Experimental design used in production of rice cakes for various test and compositional variables (BR, BR + 1% sugar at 18% tempering)

Sample details	Moisture (%)	Cooking time (s)	Temperature (°C)
BR			
0 (Production)	17.5	4	265
1 (Control)	18	4	258
2	18	2	258
3	18	6	258
4	18	4	248
5	18	4	268
6 (Control)	18	4	258
BR +1% sugar			
7	18	2	258
8	18	6	258
9	18	4	248
10	18	4	258
11	18	4	268

Each cake sample was tested at five points selected randomly and from the resultant measurements average values are presented for all of the variables tested. A typical graph showing the texture measurements taken for an individual sample is presented in Figure 8.1. Typically, the curve obtained appears to be irregular and jagged and is idiosyncratic in nature consistent with the observations previously reported for food samples expected to have similar characteristics (Laurindo and Peleg 2007).

Based upon the level of variability in the individual curves shown in the example presented in Figure 8.1, the results indicated that the compressive force-displacements curves are typical of those previously reported for brittle puffed cereal and snacks. The curves for texture measurement wide force fluctuations and show varying appearance of the individual curves. Micro-structural elements particularly the presence of air bubbles and cells contribute greatly to quality characteristics of the food product. The structure of rice cakes is that of a cellular, brittle material, based upon the appearance of the force-displacement texture curves and there are large differences between the five curves generated for one cake. Accordingly it was decided that the results reported in this chapter would be presented in the form of data prepared as an average of the five sets of data for each sample.

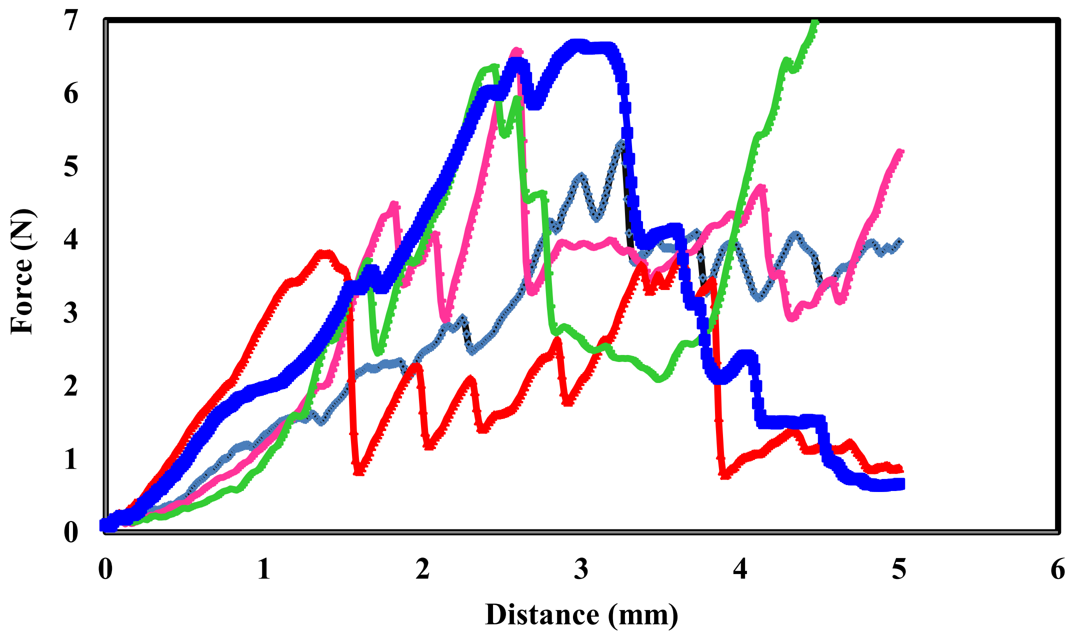


Figure 8.1 Graphical presentation of texture readings for an individual rice cake for measurements taken at five different points selected randomly

8.3 Effect of mould temperature on texture of rice cakes made from BR, WR, BR +1% oil or sugar at varying tempering levels

This section presents the results for force-displacement texture curves for rice cakes made from BR and WR at different mould temperatures having different tempering levels.

The effect of temperature on the force required to compress rice cakes made from BR at 16% tempering with the 2mm diameter probe (Figure 8.2) shows that the stiffness tends to decrease as the mould temperature increases from 248 to 268°C. However, the error bars are quite large and are overlapping (Figures 8.2 and 8.3 shown as typical examples). Therefore there is no significant difference in the stiffness during compression when the temperature increases from 248 to 268°C for BR cakes at 18, and 20% tempering and WR cakes at 18% tempering (Figures 8.3, 8.4 and 8.5). Furthermore, the addition of either 1% oil or sugar to BR at 18%

tempering (Figures 8.6 and 8.7) showed similar trends to the results for 16, 18 and 20% tempering levels. Higher temperatures tended to result in lower stiffness of rice cakes.

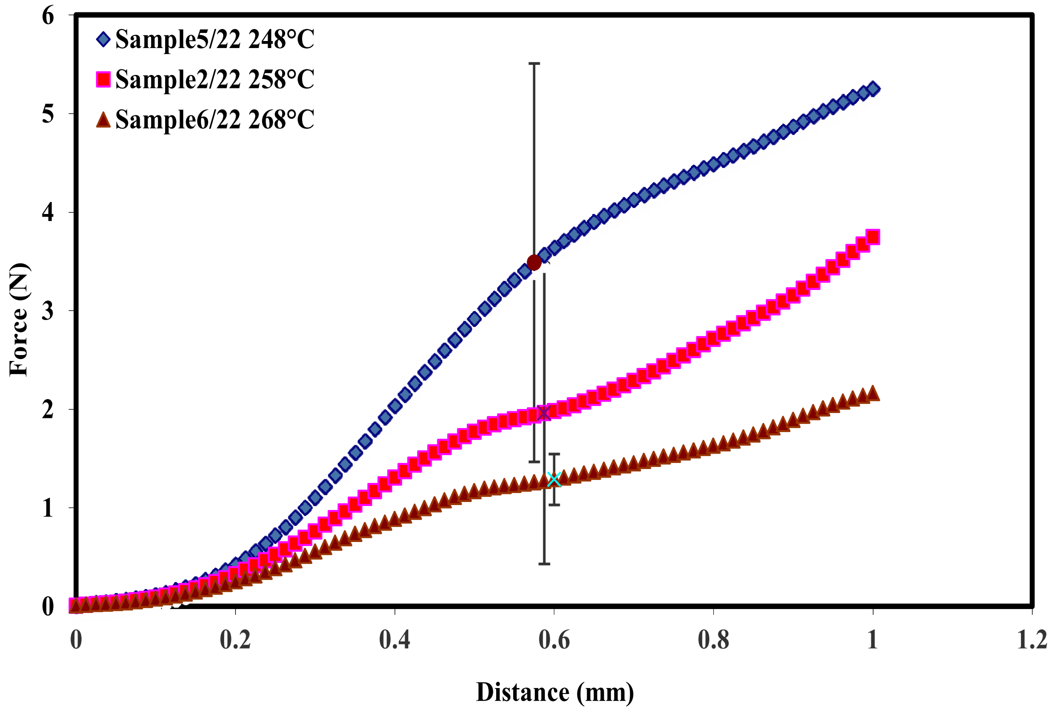


Figure 8.2 Effect of mould temperature on texture of rice cakes made from BR at 16% tempering (points on each curve represent mean of the five readings originally taken)

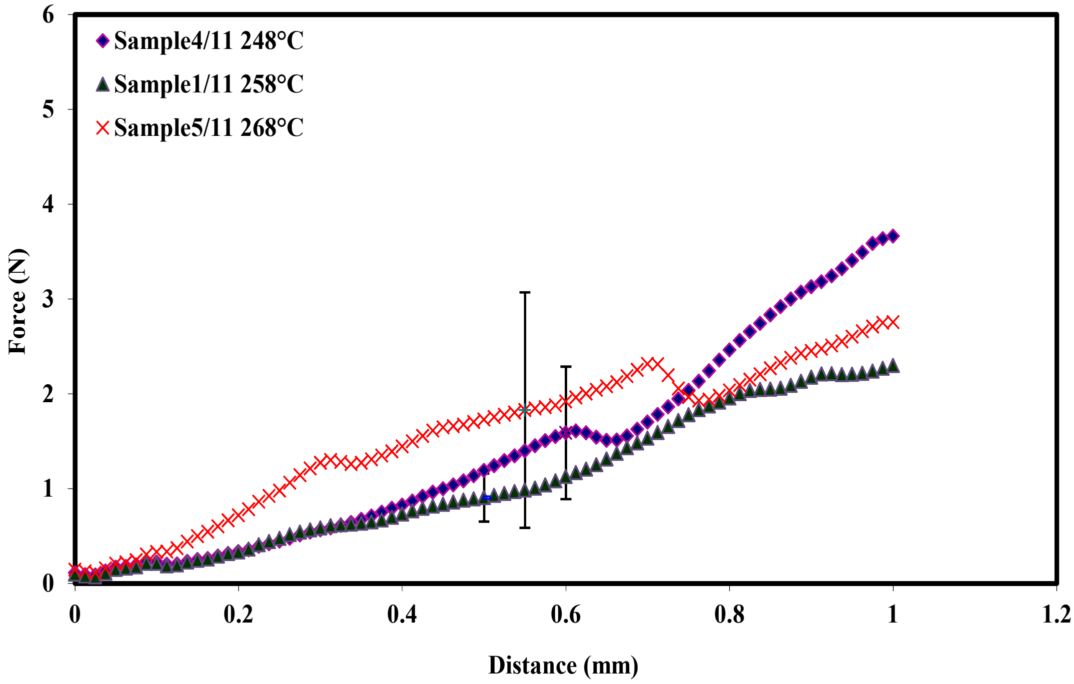


Figure 8.3 **Effect of mould temperature on texture of rice cakes made from BR at 18% tempering (points on each curve represent mean of the five readings originally taken)**

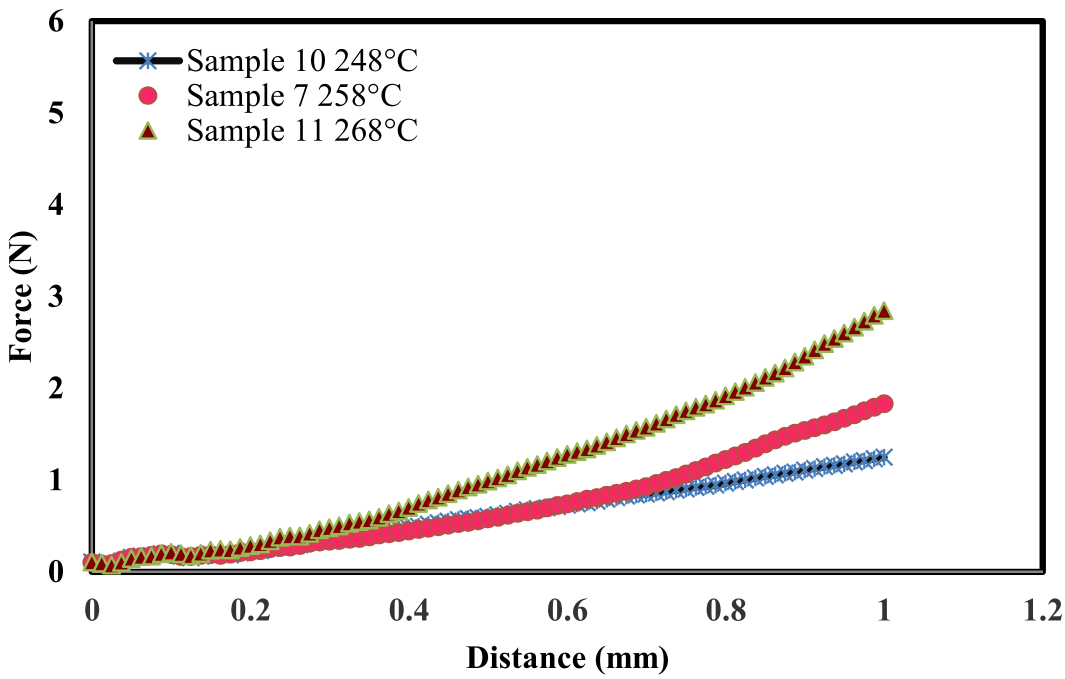


Figure 8.4 **Effect of mould temperature on texture of rice cakes made from BR at 20% tempering (points on each curve represent mean of the five readings originally taken)**

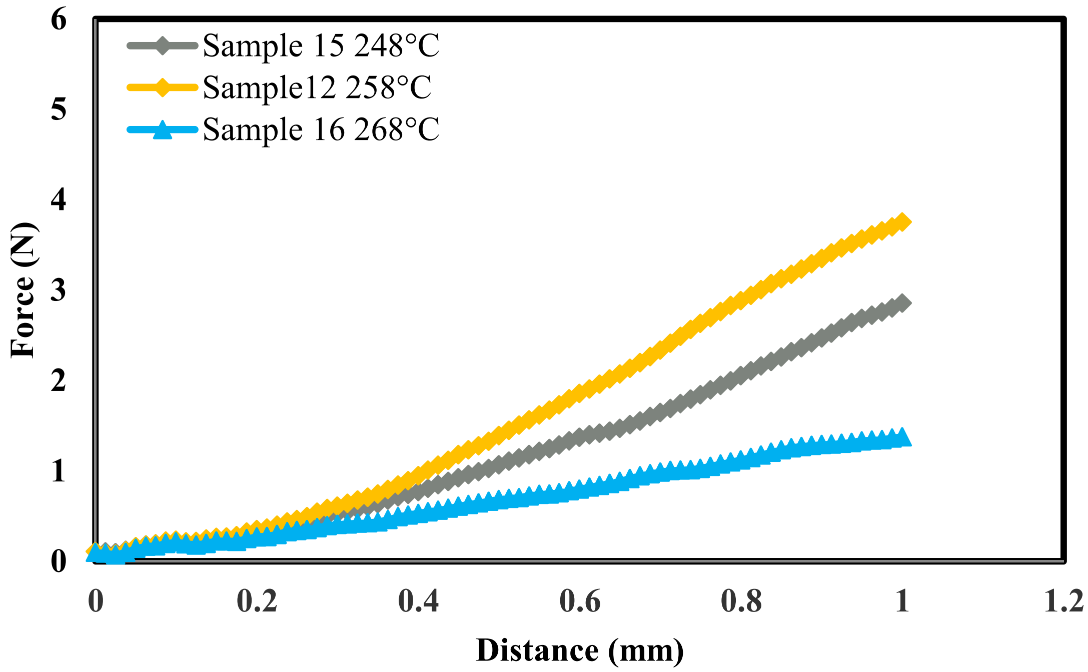


Figure 8.5 **Effect of mould temperature on texture of rice cakes made from WR at 18% tempering (points on each curve represent mean of the five readings originally taken)**

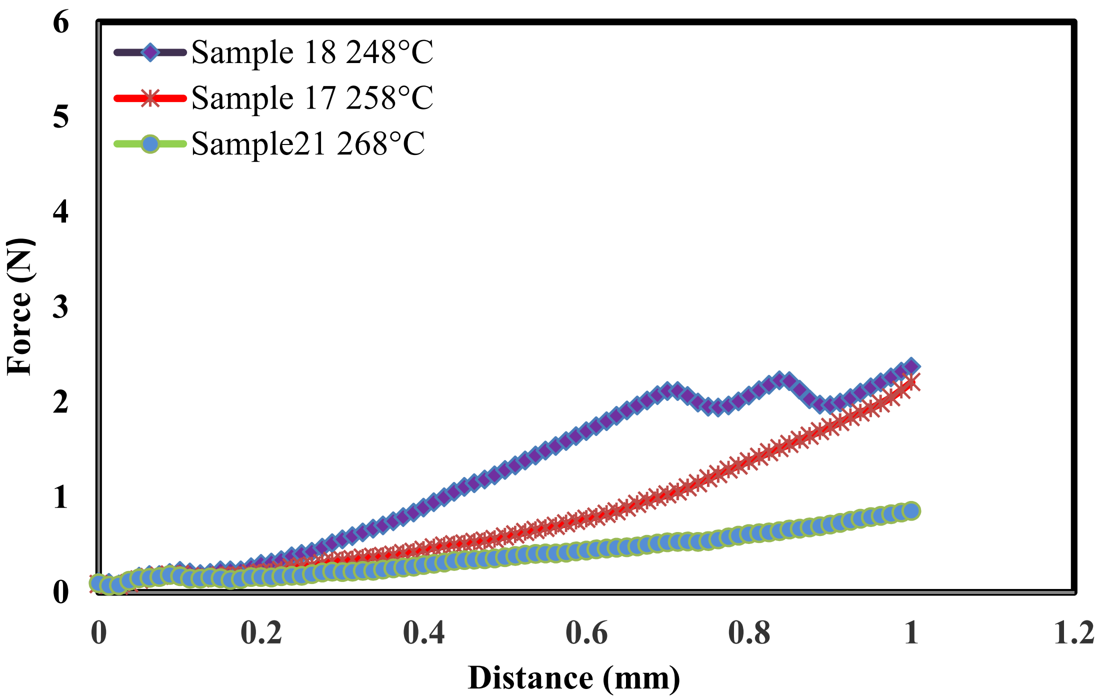


Figure 8.6 **Effect of mould temperature on texture of rice cakes made from BR at 18% tempering + 1% oil (points on each curve represent mean of the five readings originally taken)**

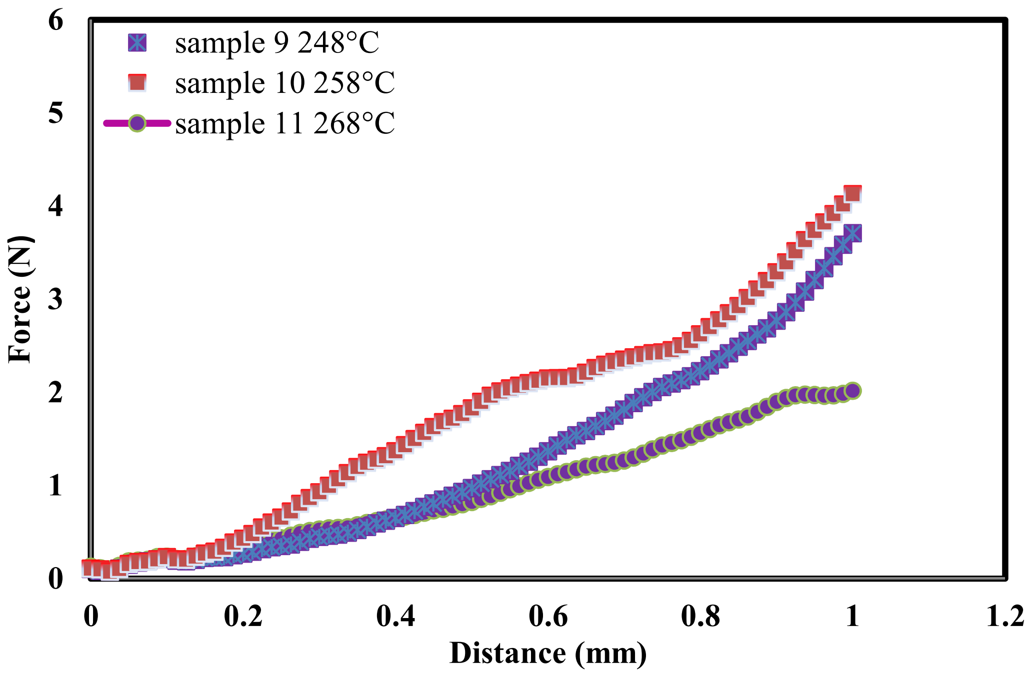


Figure 8.7 **Effect of mould temperature on texture of rice cakes made from BR at 18% tempering + 1% sugar (points on each curve represent mean of the five readings originally taken)**

8.4 Effect of mould temperature on volume and slope values for rice cakes made at varying tempering levels as well as for addition of either 1% oil or sugar at 18% tempering

In Sections 8.2 and 8.3, the variability of the patterns observed for the measurements taken for the five randomly selected positions on the surface of the cake have been demonstrated. Subsequently (Section 8.3) the data has been presented in terms of the curve generated up to that stage where the probe had penetrated 1mm into the cake. In order to facilitate evaluation of the influence of mould temperature and cake volume, particularly the relationship of these to texture of the product, the compression curves generated for all samples were plotted and the slope of the tangent of the averaged curves was calculated at a point corresponding to a penetration of 1 mm. In addition it is noted that the values for the volume of the rice cakes have already been reported in Chapter 7 and are repeated in this chapter to facilitate the evaluation of stiffness of rice cakes in relation to their volume.

The data for the effect of mould temperatures on the volume and initial slope of rice cakes are presented in a series of tables. For samples prepared at 16% tempering (Table 8.3) the results show that the volume increased and value of slope showed a decrease at the higher level of tempering. The higher heating temperatures give a higher volume for all of the processing variables as discussed in Chapter 7. The results for the corresponding values of slope for BR at 18, 20% and WR at 18% tempering show neither a marked decrease nor increase (Tables 8.4, 8.5 and 8.6). On the other hand, a reduction was observed in the value of slope for the addition of either 1% oil or sugar at 18% tempering (Tables 8.7 and 8.8).

Table 8.3 Volume and value of slope for rice cake made from BR at 16% tempering with different mould temperatures

Sample no	Mould temperature (°C)	Volume (cm^3)	Value of slope (N/mm) at 1 mm
5	248	37.9	2.8±0.4
2	258	38.0	3.1±0.6
6	268	50.8	2.2±0.7

Note Results for value of slope are presented as mean ± sd of five readings

Table 8.4 Volume and value of slope for rice cake made from BR at 18% tempering with different mould temperatures

Sample no	Mould temperature (°C)	Volume (cm^3)	Value of slope (N/mm) at 1 mm
4	248	42.7	3.5±0.5
1	258	50.1	2.4±0.5
5	268	50.8	2.5±0.6

Note Results for value of slope are presented as mean ± sd of five readings

Table 8.5 Volume and value of slope for rice cake made from BR at 20% tempering with different mould temperatures

Sample no	Mould temperature (°C)	Volume (cm^3)	Value of slope (N/mm) at 1 mm
10	248	35.9	1.7±0.4
7	258	42.1	1.7±0.5
11	268	56.0	2.7±0.6

Note Results for value of slope are presented as mean ± sd of five readings

Table 8.6 Volume and value of slope for rice cake made at 18% tempering for WR at different mould temperatures

Sample no	Mould temperature (°C)	Volume (cm^3)	Value of slope (N/mm) at 1 mm
15	248	39.3	2.8±0.5
12	258	50.9	3.6±0.4
16	268	55.8	1.5±0.4

Note Results for value of slope are presented as mean ± sd of five readings

Table 8.7 Volume and value of slope for rice cake made from BR at 18% tempering with added 1% oil at different mould temperatures

Sample no	Mould temperature (°C)	Volume (cm^3)	Value of slope (N/mm) at 1 mm
18	248	32.6	2.6±0.6
17	258	39.7	1.9±0.5
21	268	42.6	0.9±0.2

Note Results for value of slope are presented as mean ± sd of five readings

Table 8.8 Volume and value of slope for rice cake made from BR at 18% tempering with addition of 1% sugar at different mould temperatures

Sample no	Mould temperature (°C)	Volume (cm^3)	Value of slope (N/mm) at 1 mm
9	248	40.8	3.8±0.5
10	258	48.1	3.2±0.6
11	268	50.9	2.3±0.6

Note Results for value of slope are presented as mean ± sd of five readings

8.5 Summary overview of the effect of mould temperature on the textural attributes of rice cakes measured during compression

The overall effect of temperature on the texture of rice cakes compressed with a 2 mm probe is presented in Figure 8.8 which includes results for all of the samples analysed regardless of the formulation used. The figure shows a slight decreasing trend with the increase in the temperature although the correlation coefficient is very low (0.15).

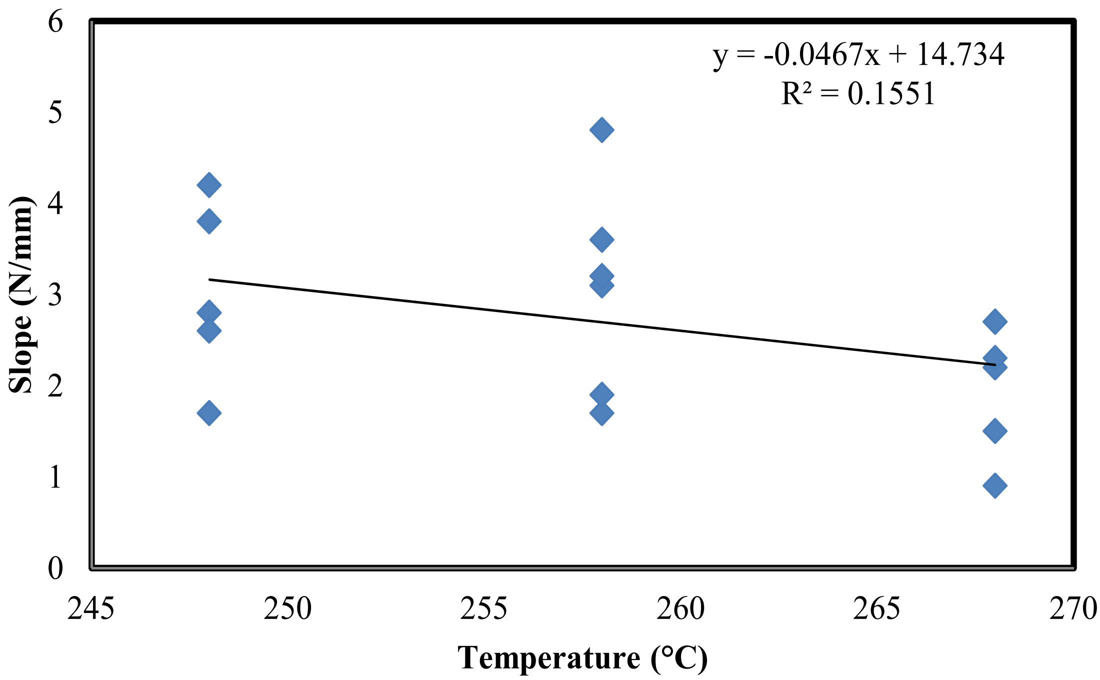


Figure 8.8 Graph showing the overall effect of different mould temperature on the slope during compression

8.6 General discussion and summary of the effect of mould temperatures on textural properties of rice cakes at different tempering levels

In summary, the effect of mould temperature on the texture of rice cakes (Table 8.9) has relatively little effect on the stiffness of the rice cakes. The individual curves of force plotted against displacement show idiosyncratic behaviour (Figure 8.1) which is typical of puffed and crisp products (Peleg 1997). There is a tendency for the structure of crisp foods to be cellular in nature. These cells contain air and the solid material that makes up the matrix within which the bubbles of gas occur are comparatively dry compared to gelled starch (Vickers and Burns 1976). When the cell wall material is very brittle the force-displacement curves can be extremely irregular and jagged, often concealing its underlying sigmoid shape of the graph. The brittleness of the structure, and consequently its deformation patterns are strongly influenced by moisture (Peleg 1997).

Table 8.9 Summary of effects of mould temperature on textural properties of rice cakes at different moisture content and rice formulations

Rice type/moisture content	Volume	Value of slope	Stiffness/textural characteristic
BR 16%	Increases	No significant trend	No significant trend
BR 18%	Increases	No significant trend	No significant trend
BR 20%	Increases	No significant trend	No significant trend
BR 18% +oil	Increases	No significant trend	No significant trend
BR 18% +sugar	Increases	No significant trend	No significant trend
WR 18%	Increases	No significant trend	No significant trend

Previous studies have reported that puffed cakes formulated with BR and added wheat starch exhibited greater flexibility and fracture strength than control rice cakes made with only BR (Orts and co-workers 2000). No other published studies provide additional clarification of comparative stiffness of rice cakes.

8.7 Effect of heating times on texture of rice cakes made from BR, WR, BR +1% oil or sugar at varying tempering levels (16, 18, and 20%)

This section presents the results obtained when heating time was varied (2, 4 and 6 sec) and the resulting effect on force-displacement texture curves for rice cakes made from BR, BR with added 1% oil or sugar as well as WR for varying tempering levels.

The effect of heating time on the force required to compress rice cake made from BR at 16% tempering with a 2mm diameter probe (Figure 8.9) shows that no changes in texture were observed when the heating time was increased from 2 to 6 seconds. Similar results were observerd for BR samples at 18 and 20% tempering and also for WR, BR with addition of either 1% oil or sugar as shown in Figures 8.10 - 8.14. The trends observed for these data were similar to those seen for varying mould temperatures.

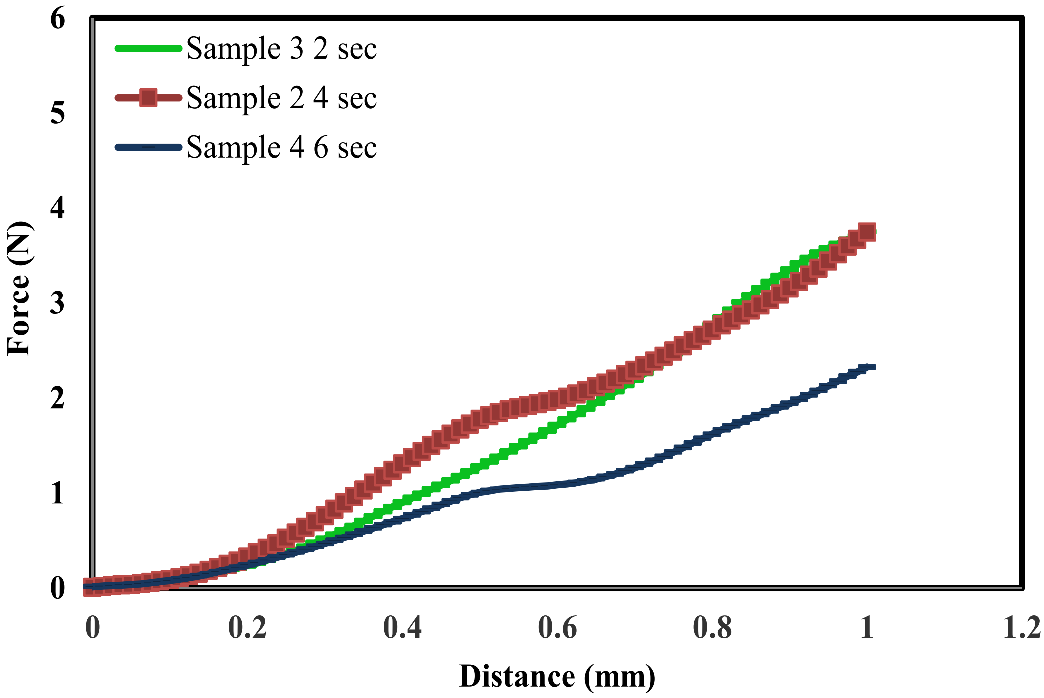


Figure 8.9 Effect of heating time on texture of rice cake made from BR at 16% tempering (points on each curve represents mean of five readings taken)

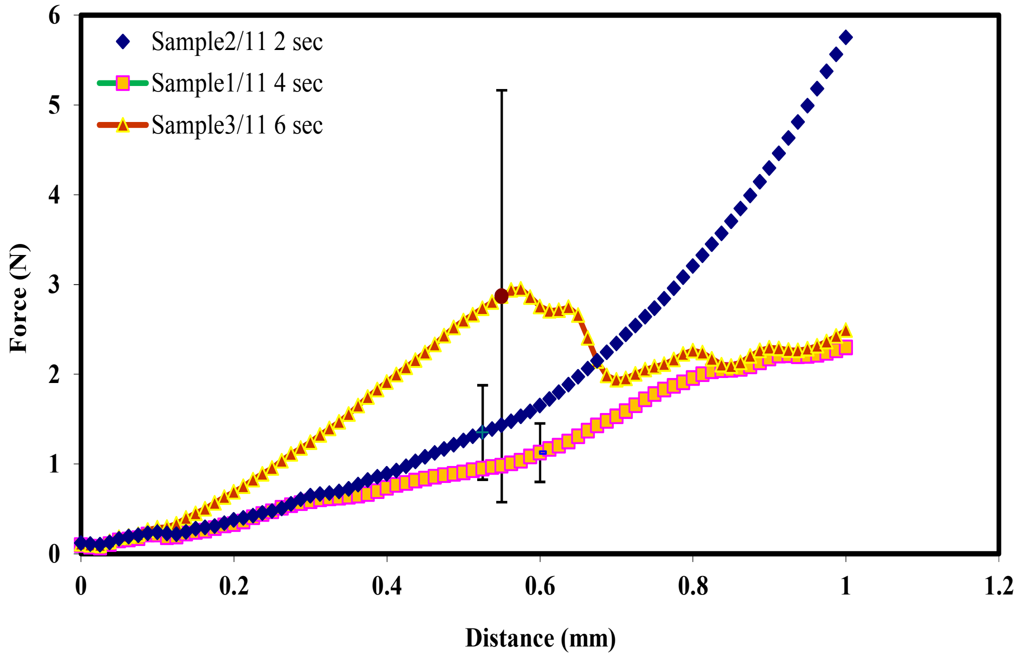


Figure 8.10 **Effect of heating time on texture of rice cake made from BR at 18% tempering (points on each curve represents mean of five readings taken)**

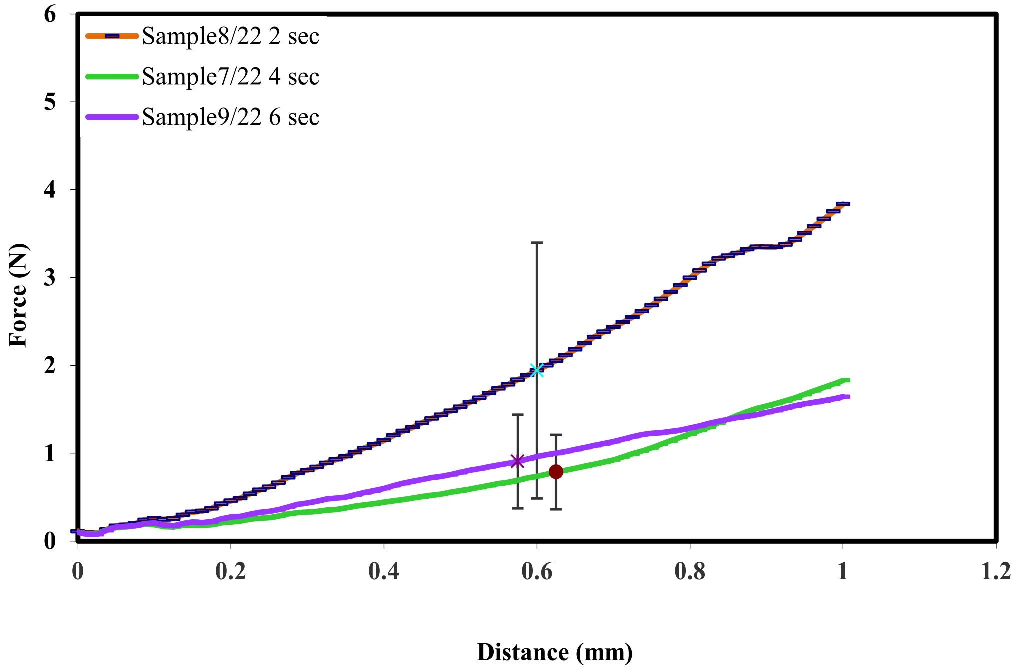


Figure 8.11 **Effect of heating time on texture of rice cake made from BR at 20% tempering (points on each curve represents mean of five readings taken)**

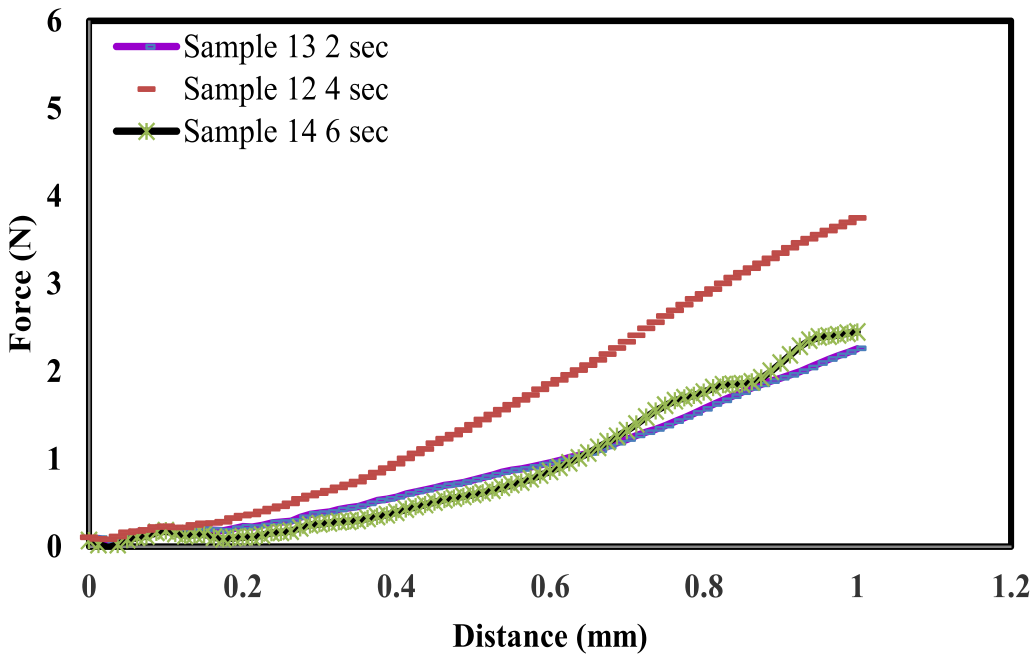


Figure 8.12 **Effect of heating time on texture of rice cake made from WR at 18% tempering (points on each curve represents mean of five readings taken)**

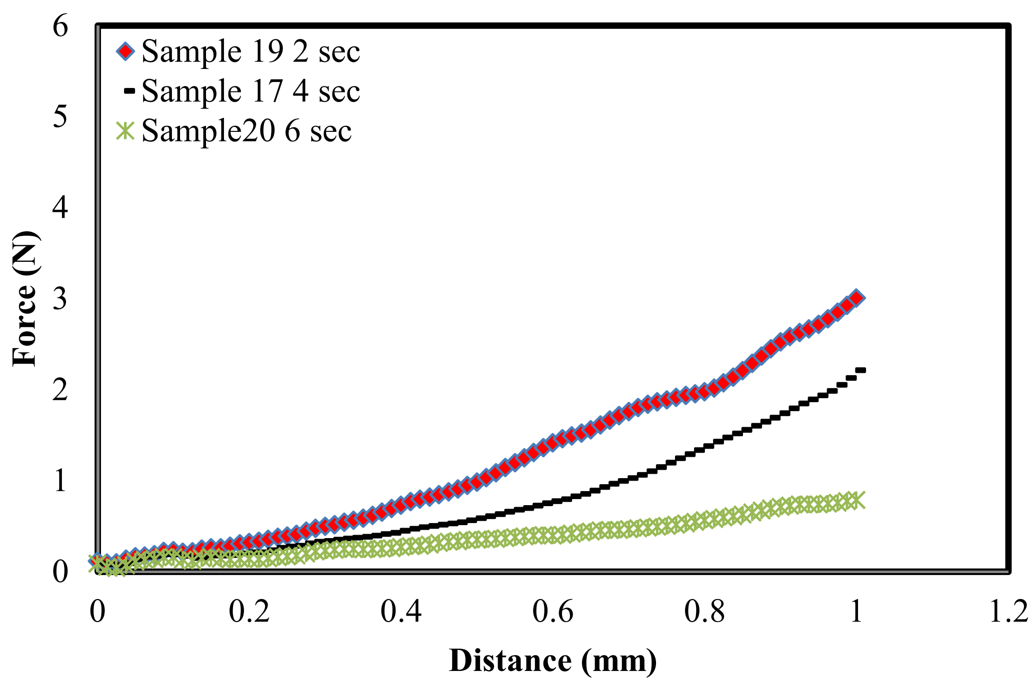


Figure 8.13 **Effect of heating time on texture of rice cake made from BR at 18% tempering with added 1% oil (points on each curve represents mean of five readings taken)**

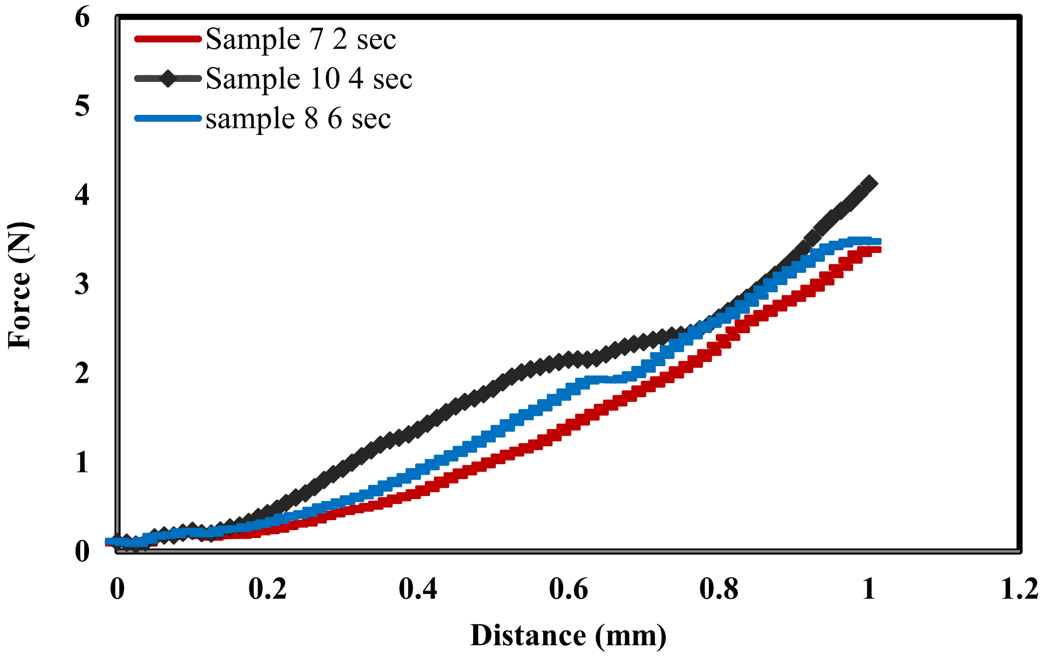


Figure 8.14 Effect of heating time on texture of rice cake made from BR at 18% tempering with added 1% sugar (points on each curve represents mean of five readings taken)

8.8 Effect of heating times on volume and slope of rice cakes made at different tempering levels of 16, 18 and 20%

This section focuses on the effect of heating time on volume and slope values of rice cakes measured during compression analysis. The results for the effect of heating time on the volume and initial slope on the texture curves (Table 8.10) at 16% tempering showed a decreasing trend in the value of slope. The higher heating time gives higher volume for all processing variables as previously discussed in Chapter 7. The results for corresponding values of slope and volume for BR at 18, 20% and 1% oil or sugar at 18% tempering also showed similar results to that at 16% tempering (Tables 8.11, 8.12, 8.13 and 8.14). The slope for WR cakes (Table 8.15) shows a higher value at 4 sec of heating time. In general the trend for value of slope is not significant and the results are similar to those for mould temperature.

Table 8.10 Volume and value of slope for rice cakes made at 16% tempering with varying heating time

Sample no	Heating time (sec)	Volume (cm^3)	Value of slope (N/mm) at 1 mm
3	2	38.0	2.8±0.4
2	4	42.5	3.1±0.4
4	6	45.6	2.0±0.2

Note Results for value of slope are presented as mean ± sd of five readings

Table 8.11 Volume and value of slope for rice cakes made at 18% tempering with varying heating time

Sample no	Heating time (sec)	Volume (cm^3)	Value of slope (N/mm) at 1 mm
2/11	2	42.7	4.8±0.5
1/11	4	50.1	3.3±0.5
3/11	6	50.8	2.2±0.6

Note Results for value of slope are presented as mean ± sd of five readings

Table 8.12 Volume and value of slope for rice cakes made at 20% tempering with varying heating time

Sample no	Heating time (sec)	Volume (cm^3)	Value of slope (N/mm) at 1 mm
8	2	51.4	4.1±0.5
7	4	42.1	1.8±0.4
9	6	54.6	1.7±0.5

Note Results for value of slope are presented as mean ± sd of five readings

Table 8.13 Volume and value of slope for rice cakes made at 18% tempering with added 1% oil at varying heating time

Sample no	Heating time (sec)	Volume (cm^3)	Value of slope (N/mm) at 1 mm
19	2	33.0	3.8±0.3
17	4	38.0	1.9±0.5
20	6	40.2	1.2±0.2

Note Results for value of slope are presented as mean ± sd of five readings

Table 8.14 Volume and value of slope for rice cakes made at 18% tempering with added 1% sugar at varying heating time

Sample no	Heating time (sec)	Volume (cm^3)	Value of slope (N/mm) at 1 mm
7	2	40.8	4.6±0.4
10	4	48.1	3.2±0.5
8	6	50.9	2.3±0.6

Note Results for value of slope are presented as mean ± sd of five readings

Table 8.15 Volume and value of slope for rice cakes made at 18% tempering with WR

Sample no	Heating time (sec)	Volume (cm^3)	Value of slope (N/mm) at 1 mm
13	2	39.0	2.9±0.5
12	4	51.0	3.7±0.4
14	6	55.5	2.1±0.5

Note Results for value of slope are presented as mean ± sd of five readings

8.9 Summary overview on the effect of heating time on the break strength of rice cakes during compression

The effect of heating time on the stiffness of rice cakes compressed with a 2 mm probe (Figure 8.15) shows only a slightly decreasing trend with the increase in the heating time. The correlation coefficient is relatively low (0.58) indicating that the slope is independent of time.

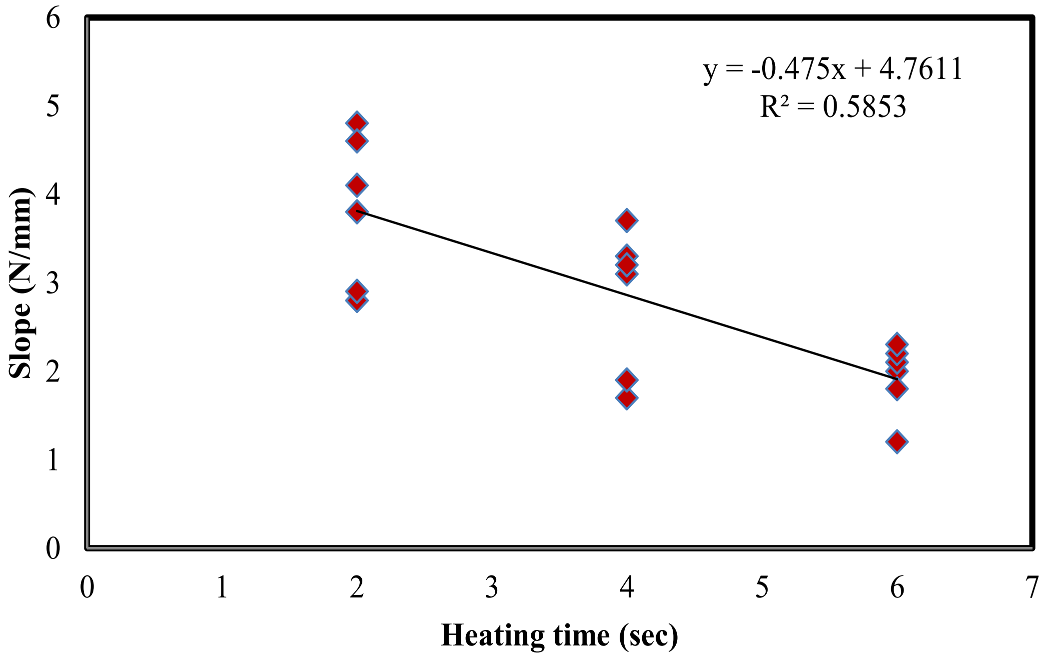


Figure 8.15 Effect of heating time on stiffness of rice cakes during compression (all samples)

8.10 General discussion and summary of the effect of heating time on textural properties of rice cakes at different tempering levels

In summary, the effect of heating time on the texture of rice cakes (Table 8.16) has no clear effect on the stiffness of the rice cakes.

Table 8.16 Summary of effects of heating time on textural properties of rice cakes at different moisture content and rice formulations

Rice type/moisture content	Volume	Value of slope	Stiffness/textural characteristic
BR 16%	Increases	No significant trend	No significant trend
BR 18%	Increases	No significant trend	No significant trend
BR 20%	Increases	No significant trend	No significant trend
BR 18% +oil	Increases	No significant trend	No significant trend
BR 18% +sugar	Increases	No significant trend	No significant trend
WR 18%	Increases	No significant trend	No significant trend

8.11 Effect of tempering levels on rice cakes made from BR

The effect of varying tempering levels on the stiffness of the rice cakes (Figure 8.16) shows that there is decreasing trend for stiffness as the tempering level is increased from 16 to 20%. The degree of "jaggedness" of compression curves depends on the moisture content (Barrett and co-workers 1994). The mechanical properties of foams typically depend primarily on the cell wall materials and cell size distribution that also controls the foam volume (Barrett and co-workers 1994).

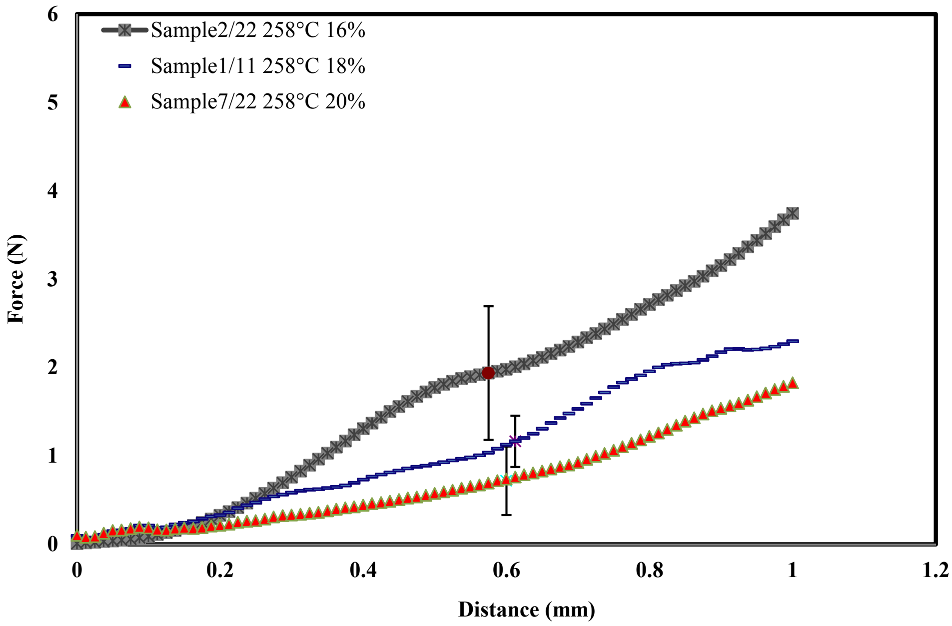


Figure 8.16 Effect of varying tempering levels on texture of rice cakes (points on each curve represents mean of five readings taken)

8.12 A comparison of BR and WR as ingredients influencing the texture of rice cakes

The previous literature indicates that no studies have been done on the use of WR for making rice cakes. BR and WR were used in the current study as a basis of comparison of the textural properties of the rice cakes The results show that stiffness appears to be higher as compared to that of BR (Figure 8.17). The bran layer in BR may effectively act as a barrier and reduce the strength of adhesion of the rice grain matrix. There appears to be no reports in the literature regarding the effect of bran on textural properties of rice cakes. In one study done by Orts and co-workers (2000) the textural characteristics of puffed brown rice cakes was modified by adding wheat starch and they suggested that addition of shortening can alter the gelatinization temperature of the rice starch depending on the structure of the lipids and their ability to form complexes with amylose.

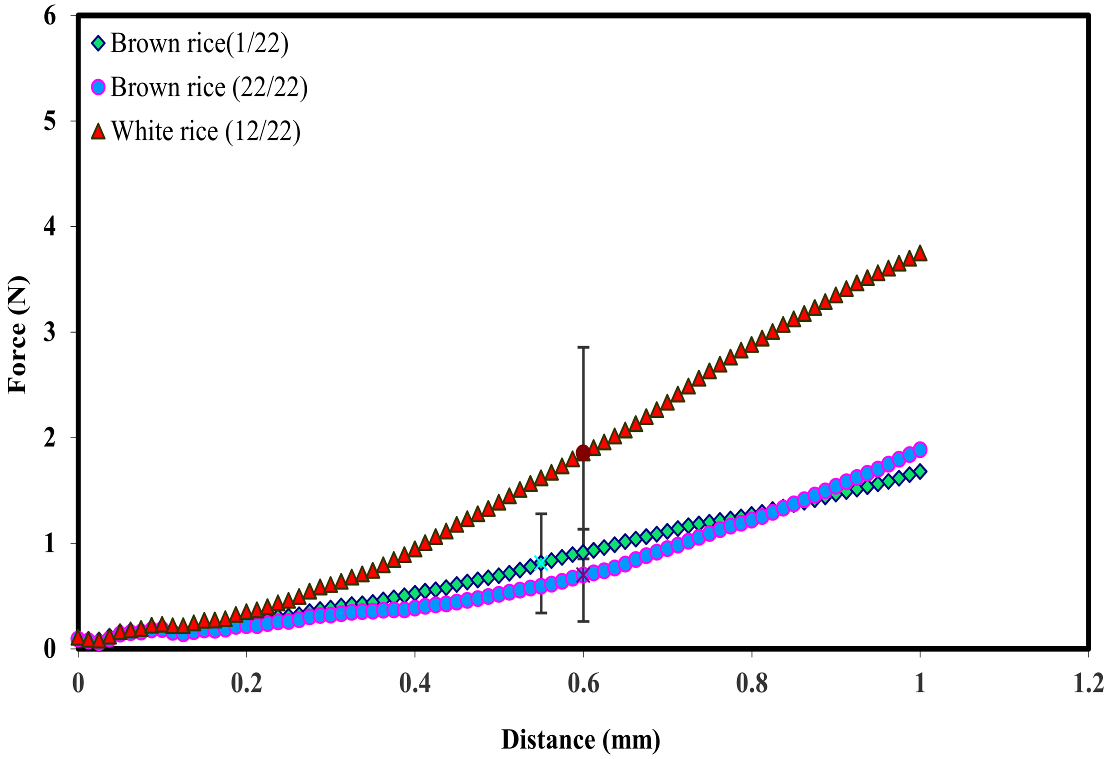


Figure 8.17 Effect of BR and WR on texture of rice cakes (points on each curve represents mean of five readings taken)

8.13 Effect of addition of oil or sugar on the rice cakes texture

The effect of oil or sugar on the stiffness of the rice cake (Figure 8.18) showed decreased stiffness in rice cakes made with added 1% oil and BR at 18% moisture. Oil was expected to reduce the strength of adhesion of rice grains during the puffing. The rice cakes made with 1% sugar showed significantly higher stiffness. This may reflect the effect of addition of sugar on the starch by increasing the gelatinization temperature. It has been suggested that this might affect volume and possibly stiffness (Orts and co-workers 2000). The same researchers speculated that adding oil may influence the gelatinization temperature of the starch by the formation of lipid-starch complexes and that these, in turn may lower the stiffness.

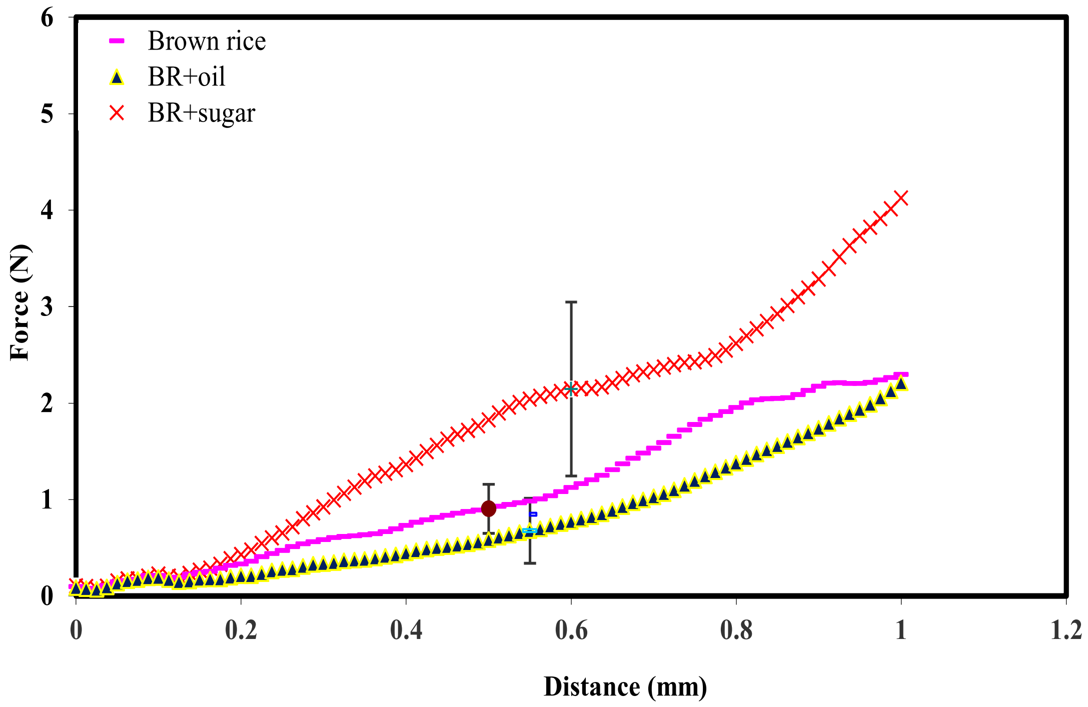


Figure 8.18 Effect of oil and sugar on texture of rice cakes made from BR at 18% moisture (points on each curve represents mean of five readings taken)

8.14 Discussion

The results of the current study indicate that the physical and mechanical properties of foam that makes up the rice cake is influenced by on compositional and processing variables. Puffed rice cakes are made up of individual puffed rice kernels that contain small air cells. The walls of the cells and the kernels are brittle, so that when indented with a texture probe the measured force is irregular. Hence texture is particularly sensitive to cellular structure, force/displacement curves are jagged and stiffness can be calculated from the slope of the force-displacement curve. Wide variation in collected data gives rise to relative high values of standard deviation. Mould temperature and heating time do no show clear effects on the stiffness of the rice cakes. This indicates that for dry and brittle solids the curves on texture measurements are too jagged to readily reveal any significant trends.

The physical and mechanical properties can also vary widely depending on the formulation. It has been stated that increased density and decreased expansion of extrudate are likely as moisture is increased (Barrett and Ross 1990; Chinnaswamy and Hanna 1988). The incorporation of food additives has previously been shown to alter the structure or strength, with citric acid reducing the density of puffed corn foam and sodium bicarbonate reducing the cell size (Barrett and Peleg 1992). In the current study, the addition of ingredients including oil appeared to lower the volume and increase the stiffness for the rice cake samples when compared to those made with the incorporation of sugar.

In the previous related studies, the addition of salt and sugar enhanced extrudate radial and axial expansion of corn meal with a twin-screw extruder, but reduced product bulk density and breaking strength (Hsieh and co-workers 1990). The use of a rice cake machine for manufacturing rice cakes with added wheat starch using BR generally increased the stiffness (Orts and co-workers 2000).

8.15 Conclusion

Very few studies have been done on texture of rice cakes. The mechanical measurements in puffed rice cakes follows the general pattern expected for cellular solids, i.e. their stress- strain relationship has a characteristic sigmoidal shape. The results in the current study show that increases in mould temperature, heating time, moisture content and change in rice formulation had relatively little effect on the stiffness of the rice cakes. The addition of oil was found to lower the volume but there was no corresponding change in the stiffness for the rice cake samples. In relation to fracture of the product, further evidence is presented in Chapter 10, along with a discussion of the mechanism of breakage of rice cakes.

Chapter 9

Results and discussion: cell size of rice cakes

The purpose of this chapter is to describe and discuss the results for the cell size distribution in rice cakes. In addition, a description of the approach taken in setting up the electron microscope and selecting the magnification for application in the current study is presented along with the images obtained by ESEM for the rice cakes made with different processing variables.

9.1 Introduction

Cell size is expected to vary with processing variables as the foam of the starch is influenced by changes in the moisture, temperature and cooking time. During manufacture the starch is heated and the steam expands so that cells of gas within the matrix grow by thermal expansion. This can be augmented by the evaporation of the water from the starch matrix into the cells as its vapour pressure rises with temperature. The pressure imposed within the hot mould causes the water to become superheated and subsequent opening of the hot mould results in a pressure drop that turns water to steam and foaming takes place, which may result in heterogeneous or homogeneous bubble growth (Gibson and Ashby 1997).

The structure of cellular foams tends to have a network that can be described as falling somewhere between perfect orders of two - dimensional honeycomb to a wide range of disordered three - dimensional networks. Natural foams show a large variation in their cell structure and texture. Rice cake foams are considered to consist of three dimensional tetrakiadecahedron (Khunniteekool undated) and the properties of the rice cake foam depend on its density and porosity. When the natural polymer starch interacts with water, the solid starch granules change into a discontinuous liquid. The amorphous and crystalline regions of the starch particles when heated are transformed from solids to a viscous liquid over a well - defined range of temperature above which the starch can be foamed or moulded.

In the current study, rice cakes were made using different combinations of the variables time - temperature as well as types of rice.

9.2 Selection of a suitable magnification and analysis of cell size observation

The magnification identified as being most useful for the study of the cell size of rice cakes under ESEM was found to be 50× with a working distance of 10mm inside the ESEM chamber, and a pressure of Torr: 5.0. The test method is described in more detail in Chapter 5. The numbers of cells were counted along a number of reference lines until a statistically significant number was obtained and each micrograph was examined for homogeneity or heterogeneity in cell size distribution.

9.3 Volume as a function of cell size

The data for volume and average cell size for all the rice cakes made using different processing variables is presented in Figure 9.1. The volume data of rice cakes has been discussed in Chapter 7. It was expected that the cell size would increase along with the increase in the volume when the mould temperature and heating time is increased. However the results showed that there is no significant correlation between the cell size and volume ($R^2 = 0.019$) of the rice cakes.

Doroudiani and Kortschot (2003) published an experimental study on the cell size distribution of polystyrene foams and found that cell density and cell size increased when the foaming time and temperature was increased. The cells formed were homogeneous in nature and it was observed that by controlling the conditions, foams having the same densities and different cell sizes and cell densities could be produced.

There is no literature available on the cell size in rice cakes. The cell size distribution in rice cakes is demonstrated in the ESEM images presented in Figure 9.2.

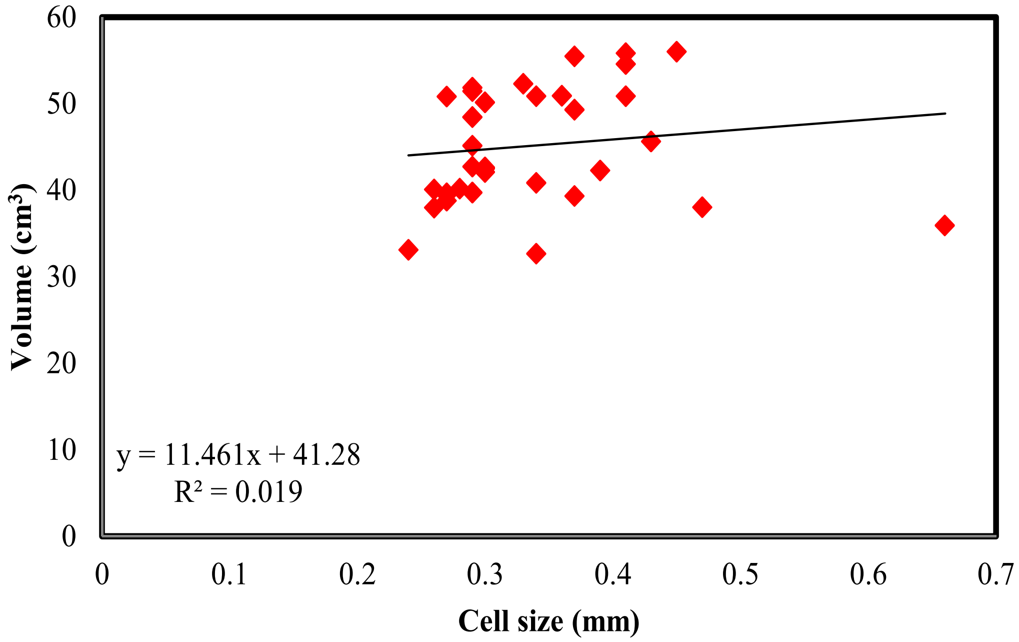


Figure 9.1 Volume as a function of cell size (all rice cake samples)

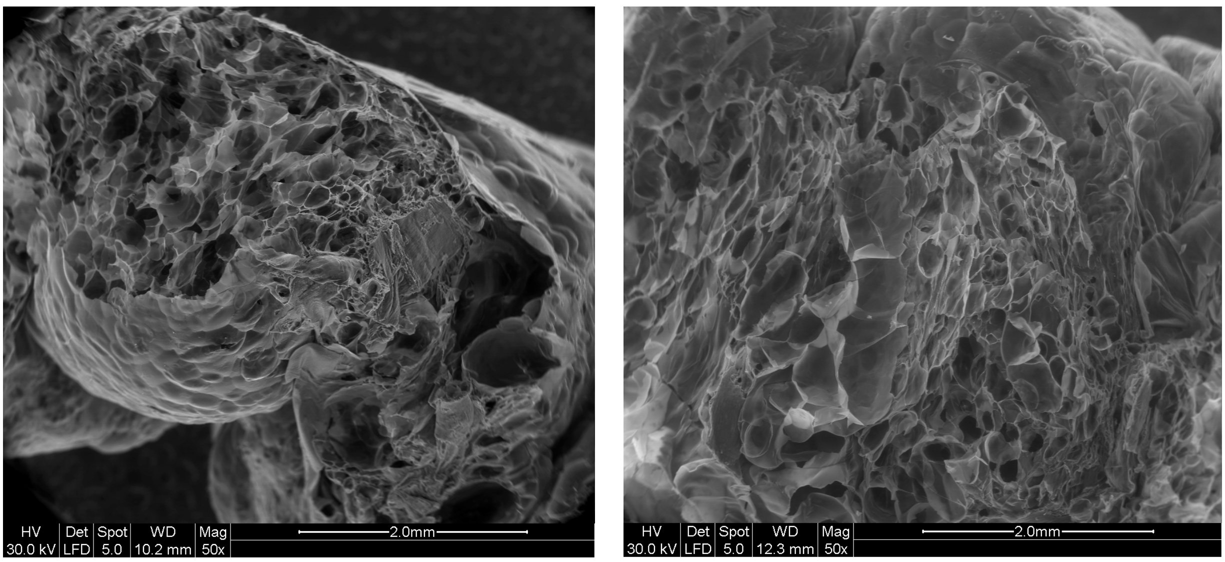


Figure 9.2 Micrographs selected as typical examples to show the variation and distribution of cell size in rice cakes

The microstructure of the rice cakes shows quite varied cell sizes. It is hypothesised that during puffing the water associated with the tempered rice grains transfers very quickly under the conditions of pressure at high temperature. This diffusion of steam from the rice starch into cells helps to control the cell size. At high temperature-time variables, more gas can diffuse into the cells, which leads to the formation of larger cells.

9.4 Effect of mould temperature on volume and cell size

The effect of mould temperature on the cell size and volume of the rice cakes made at 18 % tempering level is presented in Figure 9.3. The data indicates that when the mould temperature is increased, the volume and cell size correlated (R^2= 0.6195) as was expected.

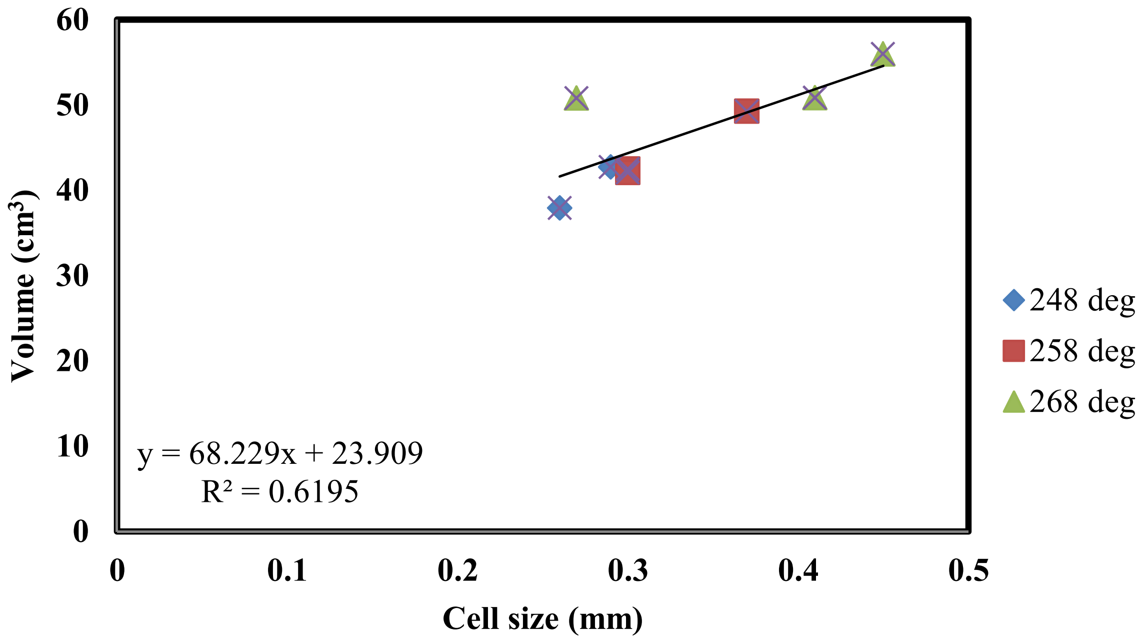


Figure 9.3 Effect of mould temperature on volume and cell size of rice cake made from BR at 18% tempering

This increasing trend can be due to the following reasons: steam diffuses due to high temperature causing thermodynamic instability and as the cells expand more, the volume also increases. When the cells are first formed they are considered to be more spherical, surrounded by a thick wall and as more steam enters the cells, due to high temperature, the expansion of the cells continues and the cell walls become thinner. Secondly, with the temperature increase, the vapour pressure increases and the number of nucleated cells also increases. An increase in the vapour pressure decreases the free energy of nucleation and hence there is an increase in the number of nuclei sites formed (Doroudiani and Kortschot 2003). An increase in nucleation is expected to decrease the cell size but increases in mould temperature have a dominant effect here, causing higher volume and larger cell size.

9.5 Effect of mould temperature on cell size

The effect of mould temperature on cell size of the rice cake made at various tempering levels of 16, 18, and 20%, as well as using WR, BR with added either 1% oil or sugar at 18% tempering is presented in Table 9.1 and Figure 9.4. The data shows no overall significant trend of cell size when the mould temperature is increased.

Table 9.1 Effect of mould temperature on cell size of the rice cakes

Mould temperature (°C)	Heating time (sec)	BR (16%)	BR (18%)	BR (20%)	BR (18%+ 1% oil)	BR (18%+ 1% sugar)	WR (18%)	Average cell size (mm)
248	4	0.26	0.29	0.66	0.34	0.34	0.37	0.37
258	4	0.30	0.37	0.30	0.29	0.26	0.36	0.37
268	4	0.41	0.27	0.45	0.30	0.34	0.41	0.37

During processing, it was expected that due to increased mould temperature the viscosity of the starch would decrease facilitating cell growth so that bigger cells might form. The results showed that there was no change in the average cell size for all the rice cakes when the mould temperature was increased at 4 sec of heating time. A comparison of the current study was made with polystyrene foams where the previous workers indicated that viscosity of the polymer decreased with increasing temperature, facilitating cell growth producing large cell size (Doroudiani and Kortschot 2003) and those results appear to contrast with those for rice cakes obtained in current study. In addition, the trend for effect of mould temperature on cell size is different to the trend seen for volume and cell size as discussed in Section 9.4

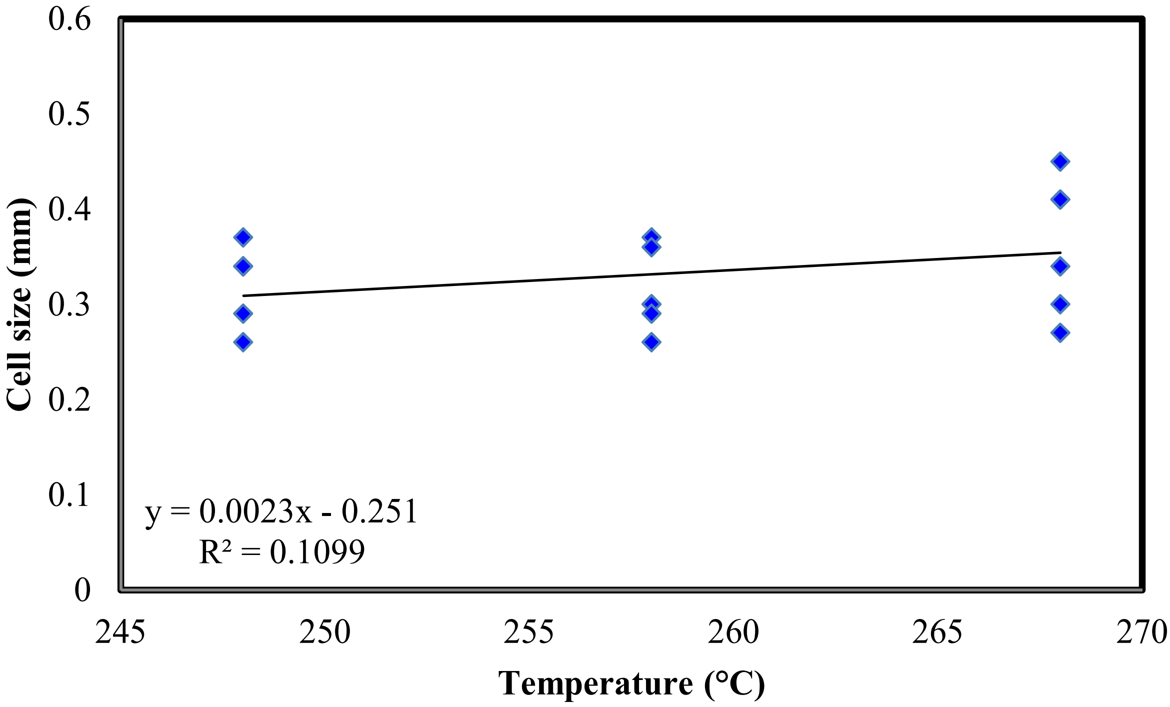


Figure 9.4 Overall effect of mould temperature on cell size of rice cake (all samples)

9.6 Effect of heating time on volume and cell size of rice cakes

The effect of heating time on cell size and volume of the rice cakes in Figure 9.5 shows that there is no clear correlation between the cell size and volume of the rice cakes when the cooking time is increased. The results are contrary to the findings of Doroudiani and Kortschot (2003) in their study on polystyrene foams. They found that cell size increased when the foaming time was increased from 10 to 30 seconds and cell size was more strongly influenced by foaming time. They also indicated that when foaming time was increased, more gas molecules diffused from the polymer matrix into the cells during expansion and hence cell density was decreased.

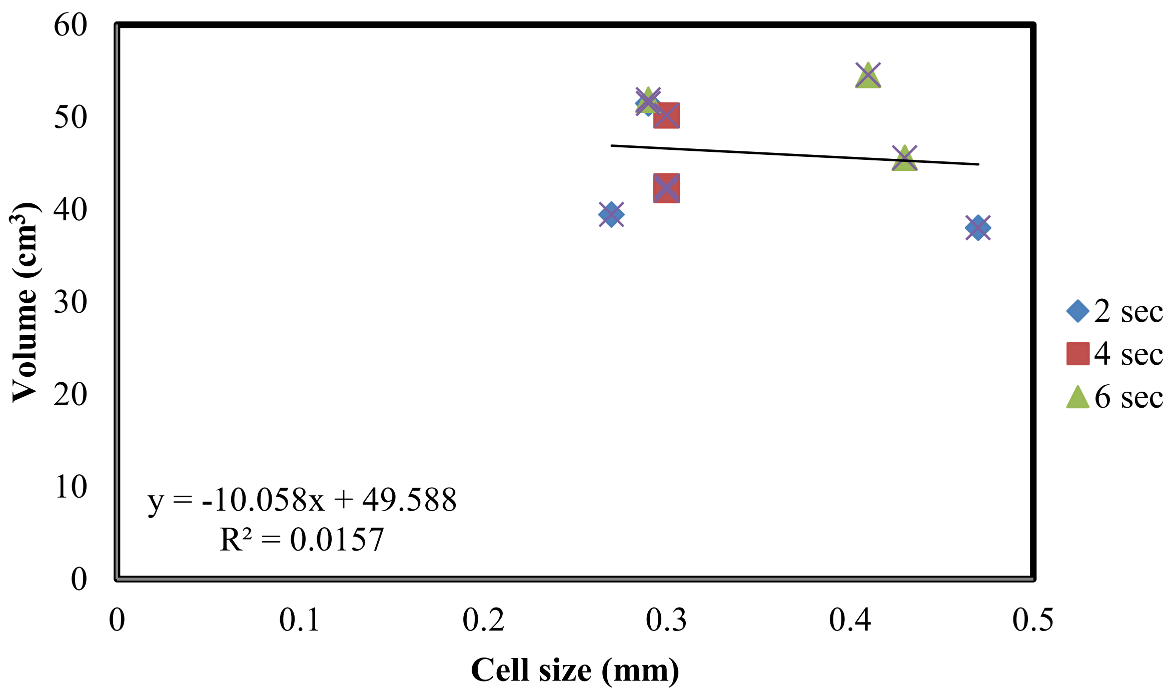


Figure 9.5 Effect of heating time on volume and cell size of rice cake made from BR at 18% tempering

9.7 Effect of heating time on cell size of rice cakes

The effect of heating time on cell size of the rice cakes made from a variety of formulations is presented in Table 9.2 and Figure 9.6. The result show that there appears to be a slight upward trend in the cell size when the heating time is increased but it is not significant (R^2=0.12). It was expected that cake volume and cell size would be correlated.

Table 9.2 Effect of heating time on cell size of rice cakes

Heating time (sec)	Mould temp (°C)	BR (16%)	BR (18%)	BR (20%)	BR (18%+ 1% oil)	BR (18%+ 1% sugar)	WR (18%)	Average cell size (mm)
2	258	0.47	0.27	0.29	0.24	0.27	0.27	0.30
4	258	0.30	0.30	0.30	0.29	0.26	0.36	0.30
6	258	0.47	0.29	0.41	0.28	0.33	0.37	0.36

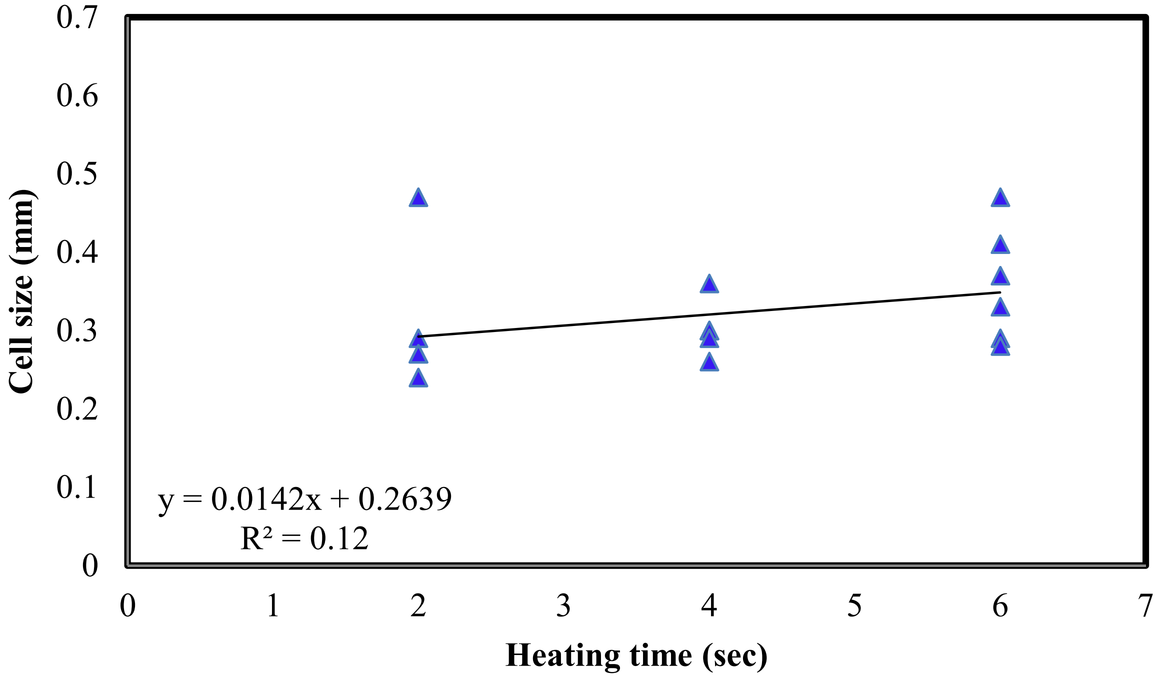


Figure 9.6 Overall effect of heating time on cell size of rice cake (all samples included)

9.8 Effect of tempering level on volume and cell size for cakes made from BR

The volume as a function of cell size for rice cakes made from BR at different tempering levels is shown in Figure 9.7 and it is observed that there is no significant trend of volume with cell size.

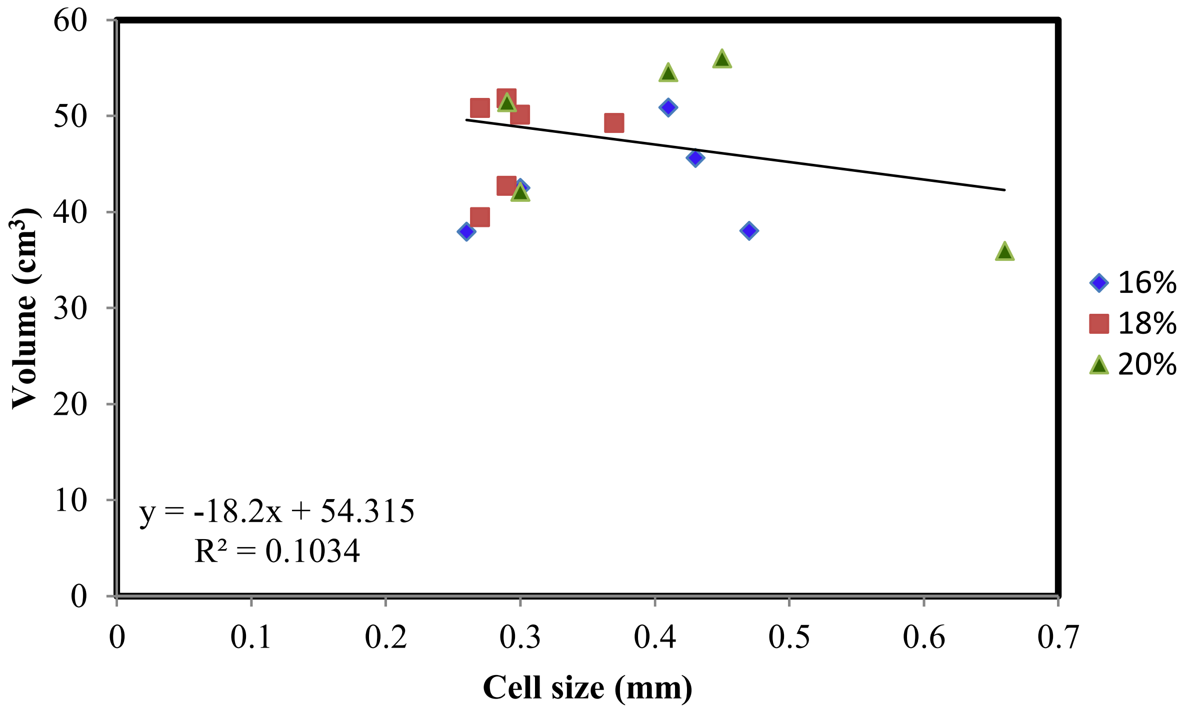


Figure 9.7 Effect of different tempering levels on volume and cell size of rice cake

Figure 9.8 presents the effect of tempering level on the cell size of the cakes and indicates no clear relationship of tempering level to that of cell size (R^2= 0.21). The data presented in Figure 9.7 shows that the relationship between the cell size and volume independent of tempering levels.

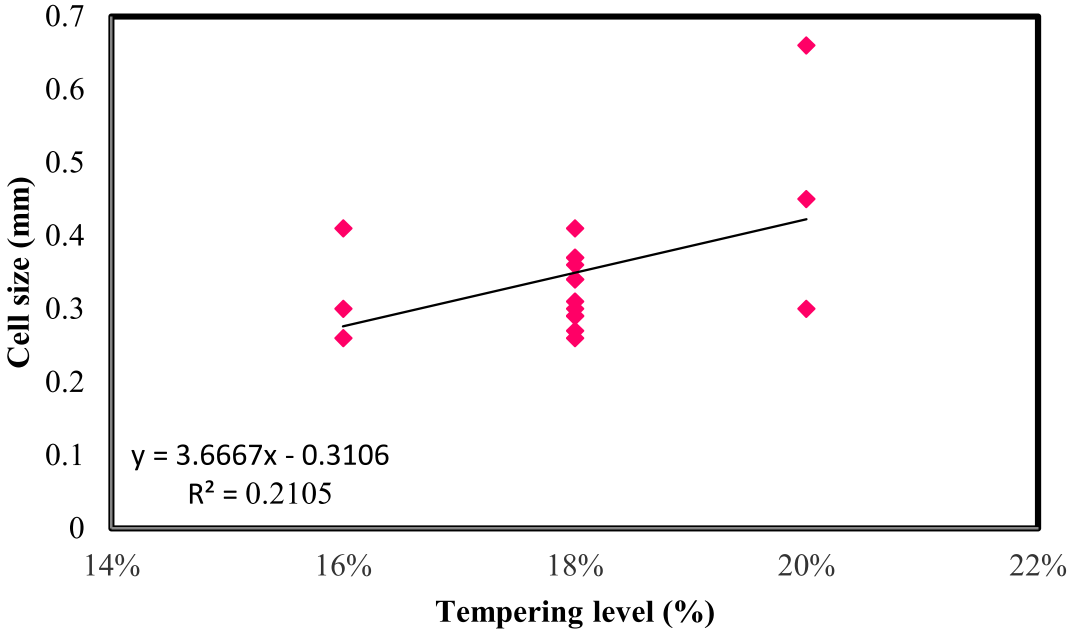


Figure 9.8 Effect of tempering levels (16, 18, 20%) on cell size of rice cake

The structure and mechanical properties of brittle starch foams appears to depend on the level of water which controls the expansion of the foams as well as effecting gelatinization temperature (Warburton and Donald 1992). It is also be possible that an increase in the moisture levels may lead to increase in the volume but cell size does not always increase with the increase in the volume of the rice cake (Doroudiani and Kortschot 2003). Rice starch granules which are polygonal in shape are compactly packed in the translucent endosperm and are loosely packed in opaque areas of endosperm (Juliano 1985) and this may result in variations in nucleation and growth of cells when starch granules in the rice are heated.

9.9 Cell heterogeneity

A typical micrograph of rice cakes shows a heterogeneous cell size distribution i.e. a mixture of both small and large cells (Figure 9.9) and from the image it appears that areas of small dense cells are clustered together and these are surrounded by areas of relatively large cells with a low density of nucleation sites. There does not seem to be a consistency in the pattern of large and small cells.

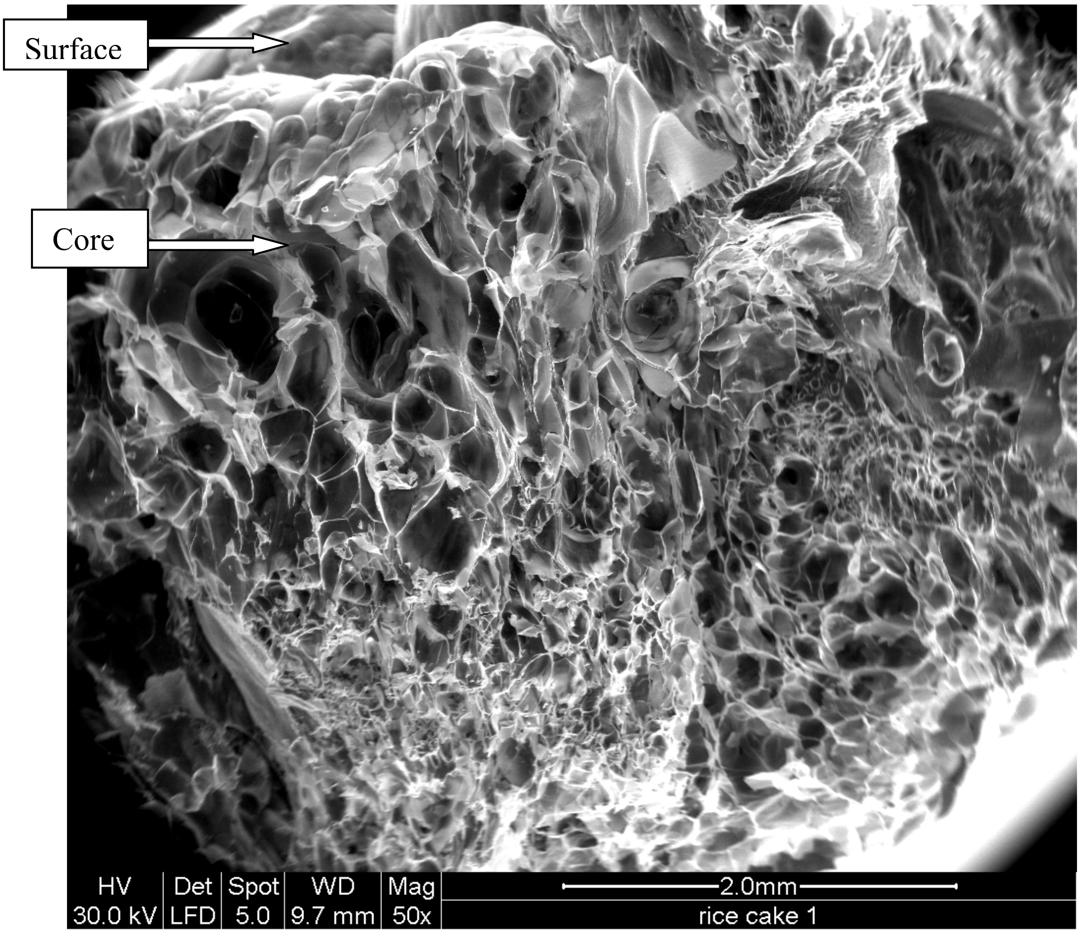
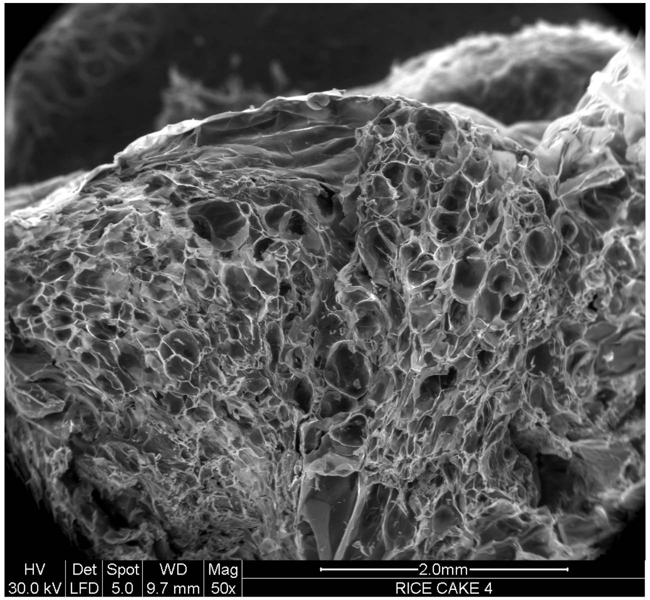


Figure 9.9 Cross-sectional ESEM image of a rice cake made from BR showing cells having a range of sizes

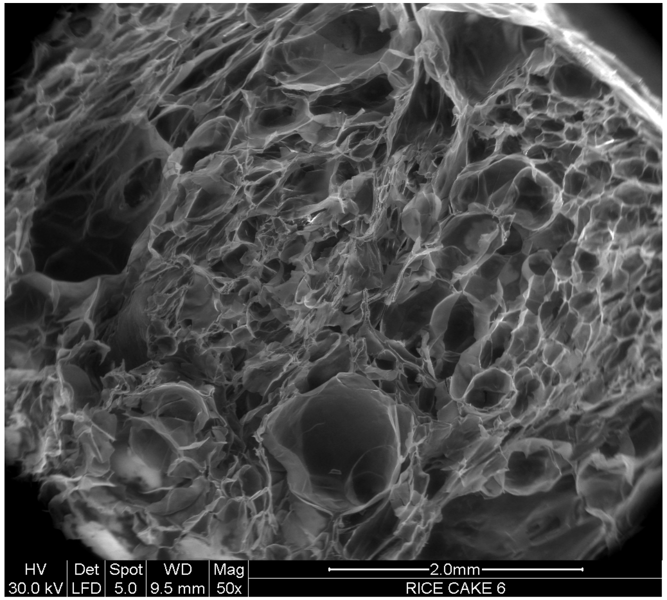
Notes Mould temperature: 258°C;
Heating time: 4 sec;
Tempering level: 18%

9.10 Cell distribution in rice cakes at varying processing variables

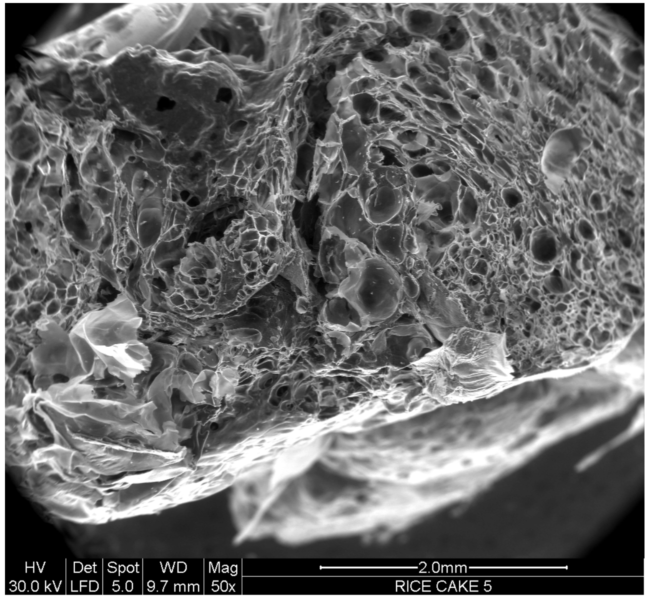
The cross-sectional ESEM images of rice cakes manufactured using different processing variables is shown in Figures 9.10 - 9.13. All of the ESEM images show a heterogeneous distribution of cell size regardless of the parameters applied during processing.



Rice cake made at 248°C



Rice cake made at 258°C

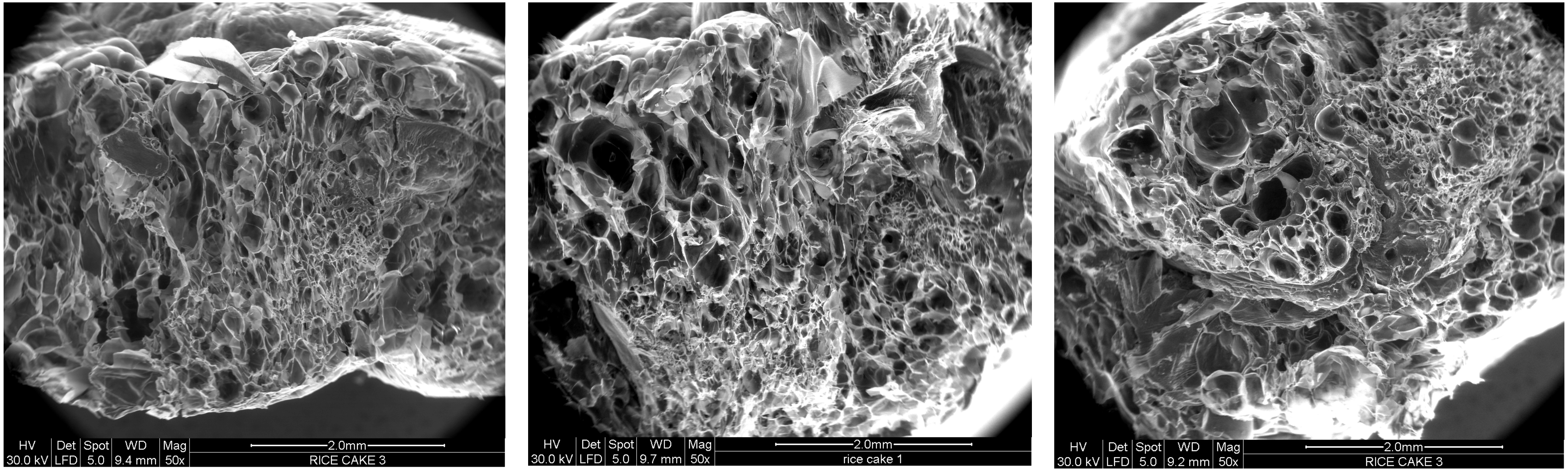


Rice cake made at 268°C

Figure 9.10 Cell distribution in rice cakes made from BR at varying mould temperature

Notes Heating time: 4 sec

Tempering moisture: 18%

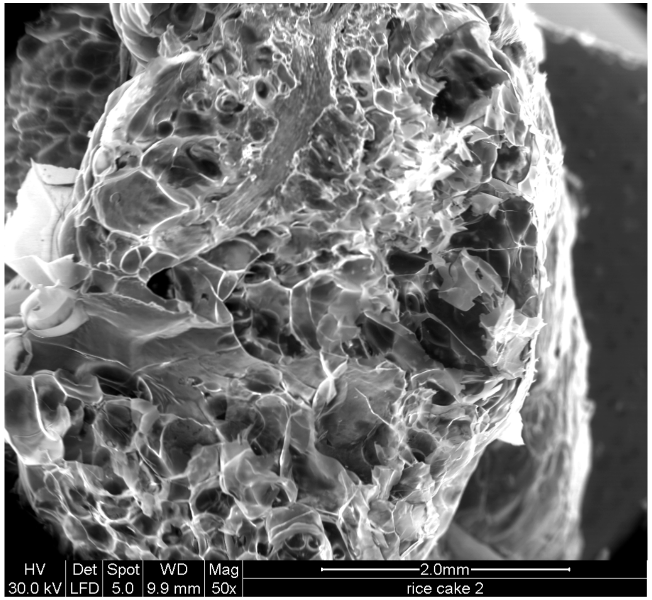


2 sec   4 sec   6 sec

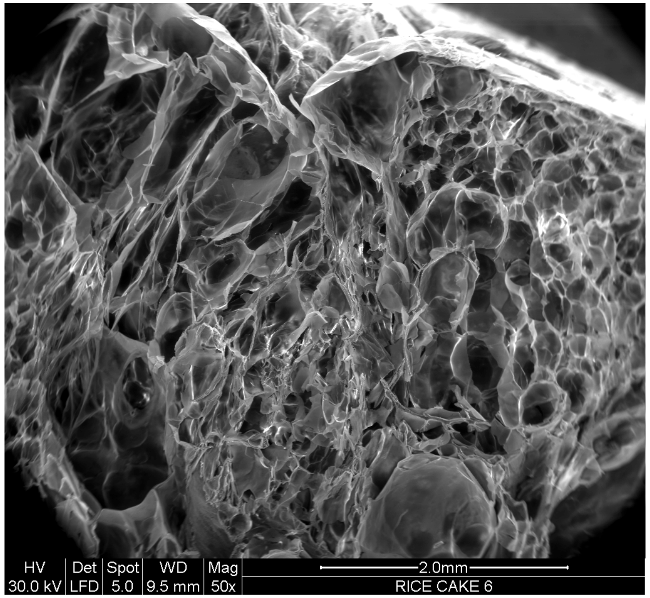
Figure 9.11 Cell distribution in rice cakes made from BR at varying heating times

Notes Mould temperature of all rice cakes: 258°C

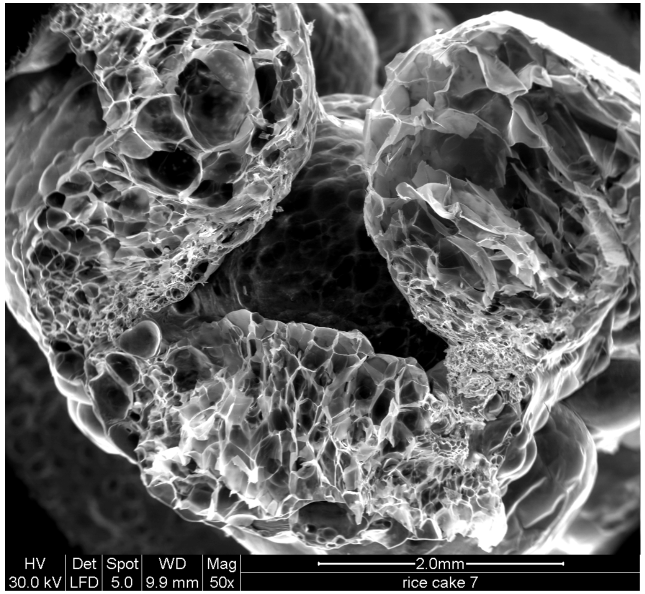
Tempering moisture: 18%



16% tempering moisture



18% tempering moisture

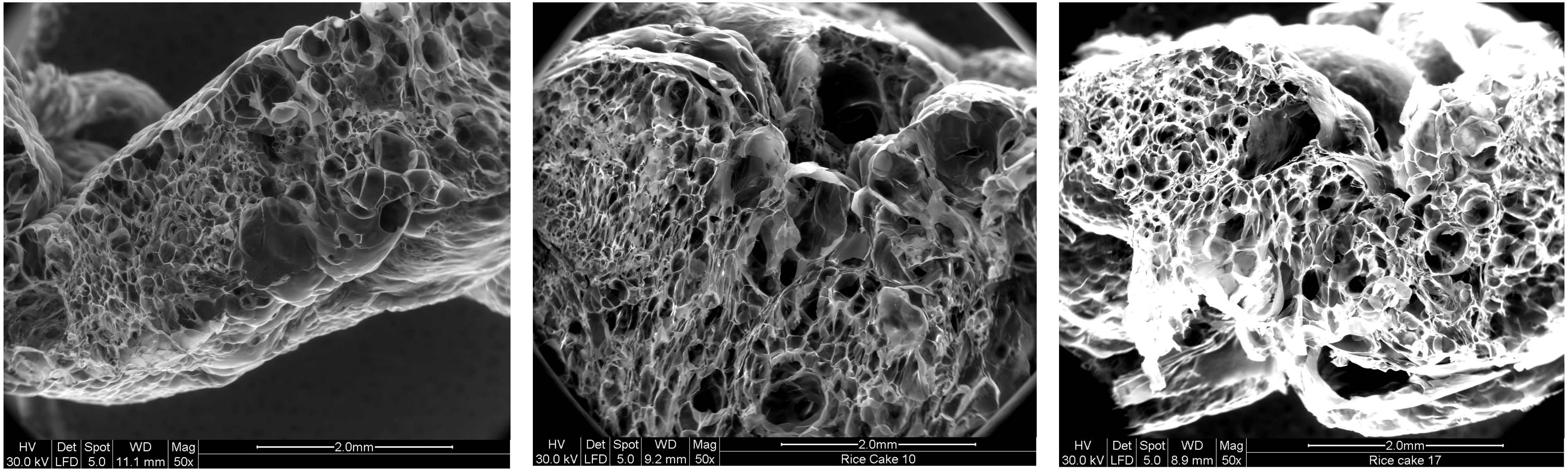


20% tempering moisture

Figure 9.12 Cell distribution in rice cakes made from BR at varying tempering levels

Notes Mould temperature: 258°C

Heating time: 4 sec



WR | 1% sugar | 1% oil

Figure 9.13 Cell distribution in rice cakes made from WR, BR with added 1% sugar or oil

Notes
Mould temperature: 258°C;
Heating time: 4 sec;
Tempering moisture: 18%

Past publications in this area do not present any theories or information on the internal structure of the puffed rice cakes. A few closely related studies describe procedures and mathematical models to characterize the cell size distribution in order to provide a quantitative description of the cellular structure of puffed corn extrudates (Barret and Peleg 1992) and the processing conditions affecting the structure in polystyrene foams (Doroundiani and Kortschot 2003).

The study of the micro structure i.e. cell size variation or distribution in the current study can depend on a number of factors:

1. The surface of rice kernel. There is a variation in pericarp, seed coat and aleurone layer due to crushing. The thicker the pericarp, seed coat and aleurone layer, the slower the steam diffusion. Milling may affect the outer layer of rice grain.

2. There can be different arrangements of the starch granules in the endosperm region of the rice kernels. The rice generally contains polygonal starch granules arranged compactly with no intergranular space; whereas the opaque endosperm contains loosely arranged spherical starch granules with intergranular spaces (Juliano 1985). For other cereals, wheat contains starch granules which are either spherical or flattened spheres along with gluten to fill in the spaces and sorghum contains round starch granules. The more space between the granules, the higher the rate of steam diffusion, which may affect the degree of puffing.

3. Chalkiness of the rice kernel varies within and between rice kernels. The starch granules are loosely packed at the ventral side of the germ and the chalky rice grains have low amylose content. The rice used to make rice cakes for this study was low amylose rice and there was some degree of chalkiness present in some of grains. The chalkiness could cause fast diffusion of steam and may result in small cell size distribution. The term 'mottled grain' is often used to refer to chalkiness for other cereal grains.

4. There can be variation in hardness of the grain and rice used in this project was a medium hardness variety and is considered to be resistant to climatic changes and is best suited to rice cake manufacture. Literature describes hard grain as being

comprised of starch granules which are compactly packed to provide resistance to premature escape of steam (Juliano 1985).

Murugesan and Bhattacharya (1991) found that the contents of amylose and protein in rice had no effect on the "popping" (expansion) of BR. There is no mention of the effect of bran/lipids on the popping by the authors although it is expected that the chalkiness and hardness of rice reduce the popping expansion but the pericarp thickness and seed coat have no effect on popping expansion.

In the current work it is likely that the bran layer may reduce diffusion so higher pressure builds inside the rice grain at the time of puffing giving heterogeneous cell size distribution.

It is also observed in the current study that the expansion of rice grains is primarily confined to the endosperm; in all of the micrographs it was consistently seen that the sub - aleurone portion expanded little and there appeared to be no change in germ and aleurone layers of the rice. Similar observations were made for popped corn (Hoseney and co-workers 1983) and sorghum (Harbers 1975).

9.11 Conclusion

Natural foams show a wide variation in their cell structure and texture. From the processing trials in the present study it has been identified that the starch behaviour and tempering moisture were important and these in turn affected the cell size and its properties. The results indicated that independent of mould temperature, the volume and cell size showed a correlation (R^2= 0.6195) i.e. with the increase in volume of the cakes the cell size was also increased.

The volume and cell size of cakes showed a correlation when the mould temperature was increased and there appears to have been no clear relationship between mould temperature and cell size. Also there was no correlation seen between the cell size and volume of the rice cakes when the cooking time was increased.

The effect of tempering level on cell size and volume of cakes showed different results. Firstly, there appears to have been no correlation between cell size and volume when the tempering level was increased from 16 to 20% for all processing variables. Secondly, the data on cell size and tempering level showed an upward trend. To summarise the results for all the test variables, the cell size observed was very heterogeneous in nature.

The heterogeneity of the cell size may be due to a number of contributing factors including as the variation in the steam pressure, time and temperature variables, crushing of the rice grains during processing, arrangements of the starch granules in translucent and opaque regions of endosperm, presence of inter-granular spaces in the opaque region of the endosperm, presence of chalkiness and the presence of the bran.

There are no literature reported which can support that which factors affect the cell size of rice cakes. Hence the current study of cell size in rice cakes has provided novel quantitative information to enhance understanding of the complex changes that rapidly occur during processing of rice cakes.

Chapter 10

Results and discussion: the effect of rice type and composition on characteristics of rice cakes

This chapter focuses on rice cakes prepared using rice samples of different types and composition. The results obtained during the physical analysis of rice cakes are described and includes an investigation of protein and amylose content and their effect on the puffing and adhesion of rice cakes.

10.1 Introduction

A range of rice types are available and these vary in the shape of the grain and in addition, composition varies on the basis of genetic and environmental factors. It is possible that rice varying in types and composition may be suitable for making puffed rice cakes. The past studies primarily focussed on the use of long and medium grain brown rice for making rice cakes. The specific purpose in the current phase of this study has been to provide a basis of comparison between the rice cakes made from low and high protein rices as well as waxy rice with samples of conventional commercial rice cakes. In the evaluation of rice cake characteristics the analyses reported here are rice cake mass, thickness, volume, stiffness and colour attributes.

10.2 Composition variables

Four different samples of rice were selected:

1. Low protein brown rice
2. High protein brown rice
3. Low protein brown waxy rice
4. Reference brown rice

The rice samples were used to prepare cakes using standard processing parameters of mould temperature: 258°C; heating time: 4 sec; tempering 18%, using the rice cake machine. The equipment used was the same as those currently used in the commerical production plant. In the analysis of all samples, replicate measurements (n=10) of individual samples were recorded and the results are reported as mean value ± standard deviation.

10.3 Effect of compositional variables

The physical and structural properties of rice cakes made from rice samples of different compositions (Table 10.1) show that there is no significant difference in the mass or thickness. The cake volume of low protein waxy rice was much lower than that of other rice cakes made with low-protein, high protein and reference brown rice. This was consistent with the appearance which was thinner and less well puffed.

Table 10.1 Physical and structural properties measurements of rice cakes made from low-protein, high-protein and waxy rice

Sample description	Mass (g)	Thickness (mm)	Cake volume (cm^3)	Stiffness (N)
LPRC	8.4±0.9	6.4±0.2	47.4±0.8	6.8±0.6
HPRC	8.1±0.3	6.3±0.2	47.0±0.9	5.8±0.8
WRRC	8.3±0.1	6.0±0.1	44.7±0.8	6.5±0.5
RRC	8.1±0.2	6.3±0.3	47.0±0.9	9.2±0.8

Notes 1 Results are the mean of multiple measurements (n=10) and are expressed as mean ± sd
2 LPRC = Low protein rice cake , HPRC = High protein rice cake
WRRC = Waxy rice (low protein) rice cake and RRC = Reference rice cake

The stiffness of the rice cakes (Figure 10.1) made from the various rice compositions is significantly lower than that of the reference sample when the standard deviation values are compared.

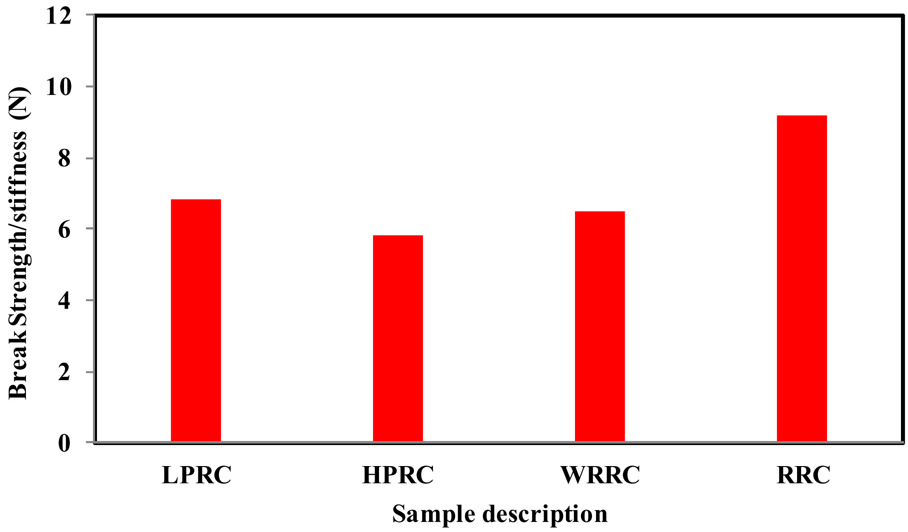


Figure 10.1 The effect of composition on the break strength or stiffness of rice cakes
Notes LPRC = Low protein rice cake , HPRC = High protein rice cake
WRRC = Waxy rice (low protein) rice cake and RRC = Reference rice cake

The results indicate that adhesion between the puffed grains in rice cakes is independent on both the protein level as well as the amylose level and there has been no previous reports in the literature which can support this observation. The reference rice cake samples (RRC) made from brown rice with tempering moisture level of 18% were found to be "optimal" in terms of cake robustness and thus stronger adhesion between puffed grains would be expected to lead to less breakage of cakes during production, shipping and storage. It is noted that there is limited literature on the adhesion of rice grains and it was reported that stickiness of rice grains cooked by steaming increased with increasing levels of the protein oryzenin (Chastril 1990). This previous report related to adhesion of cooked rice in the moist conditions.

10.4 Colour measurement

The results for colour (Table 10.2) show that there was no difference in the measured colour readings of the cakes made from sample prepared for different composition along with that of reference rice cakes. The increase in lightness value and decrease in yellowness may be related to greater rice kernel expansion (higher volume), the rice grains becoming more transparent as the cell walls become thinner. Huff and co-workers (1989, 1992) reported that rice cakes with lower specific volume had lighter or whiter colour.

Table 10.2 *L, *a**, and *b** values of rice cakes made at different rice composition**

Sample description	Volume (cm^3)	Visual observation	Lightness (L*)	Hue (a*)	Chroma (b*)
LPRC	47.41±0.81	yellow	75.42±0.02	2.13±0.02	11.93±0.01
HPRC	47.03±0.91	yellow	75.01±0.03	2.96±0.01	12.42±0.02
WRRC	44.76±0.85	yellow	70.60±0.02	1.92±0.03	15.90±0.03
RRC	47.00±0.93	yellow	77.62±0.02	2.62±0.01	11.76±0.02

Notes 1 Results are the mean of multiple measurements (n=10) and are expressed as mean ± sd
2 LPRC = Low protein rice cake , HPRC = High protein rice cake
WRRC = Waxy rice (low protein) rice cake and RRC = Reference rice cake

10.5 Study of the cellular structure of the rice cakes made from different rice composition

The texture of the rice cakes primarily evaluated by their cellular structure and the mechanical properties is also determined by the distribution of cell size within the puffed foam. This section is focussed on the internal structure of the rice cakes. In this experiments reported here, the samples were prepared by two methods:

1. By cutting the cakes through the centre using surgical blade;
2. By breaking the cakes during break strength measurements carried out using the Instron Universal Testing machine

Following the cutting or breaking, samples were inspected using the ESEM and images were recorded. Each micrograph was examined and evaluated as to whether the samples were homogeneous or heterogeneous in cell size distribution. This study also highlights the adhesion mechanism between kernels in cakes made with waxy, and low and high protein varieties.

10.5.1 Reference rice cake sample

The ESEM micrographs from reference rice cake samples for which the two different surface preparations were used, are shown in Figures 10.2 and 10.3. The rice cake sample shown in Figure 10.2 was collected during a break strength test which was broken randomly and Figure 10.3 shows the sample that was cut with a surgical blade. The two images are remarkably similar and both show a very heterogeneous distribution of cell sizes. A grain boundary can be seen in Figure 10.2 (see arrow) and this also shows a high concentration of small cells especially adjacent to what was originally the outer surface of grain of brown rice.

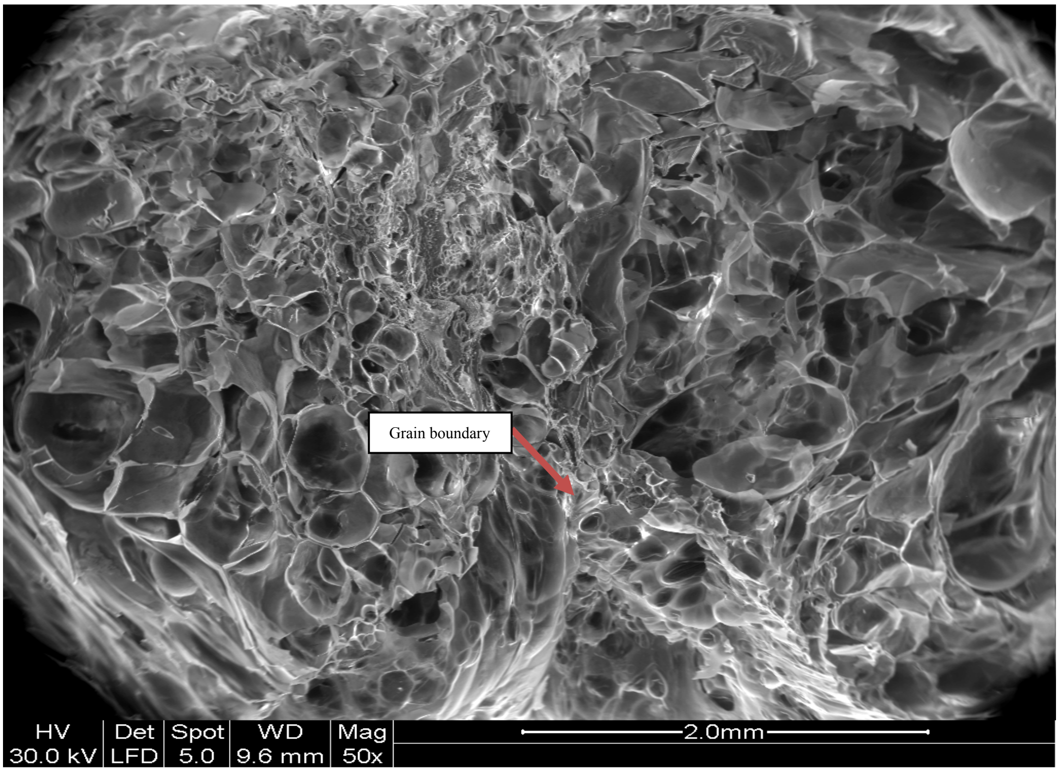


Figure 10.2 Micrograph of reference cake sample prepared by breakage

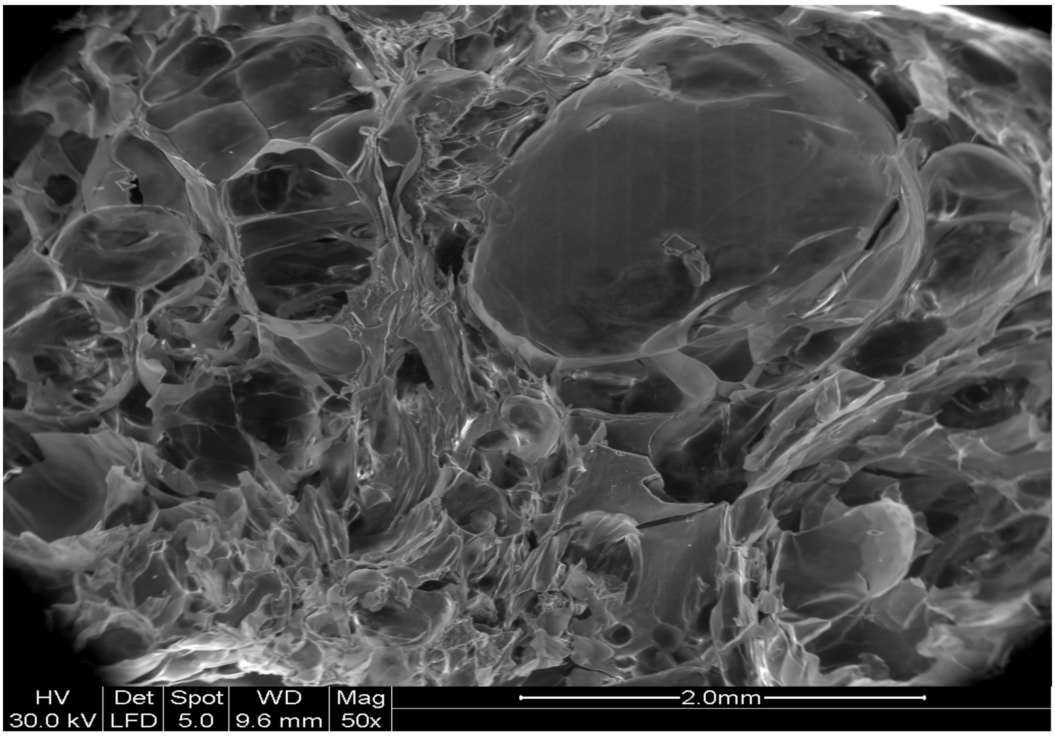


Figure 10.3 Micrograph of reference cake sample which was cut with a blade

10.5 2 White rice cake sample

Rice cakes made from white rice also were studied for cell size distribution The broken surface of the rice cake is shown in Figure 10.4 and the cut surface is presented in Figure 10.5. It was observed from the ESEM images that the cell size distribution is again highly heterogeneous which is similar to the observations for cakes made from brown rice. Most of the cell are small in size and so are densely packed across the cut surface. Some large cells are seen near the cake surface, creating a bubble-like structure on the kernel surface (see arrow, Figure 10.5).

10.6 Cell distribution in rice cakes made from different rice type and composition

Comparison in the cell size distributions were made for rice cakes made from different rice types (BR and waxy BR) and composition (low protein and high protein) and these are presented in Figure 10.6 (broken surfaces) and Figure 10.7 (cut surfaces).

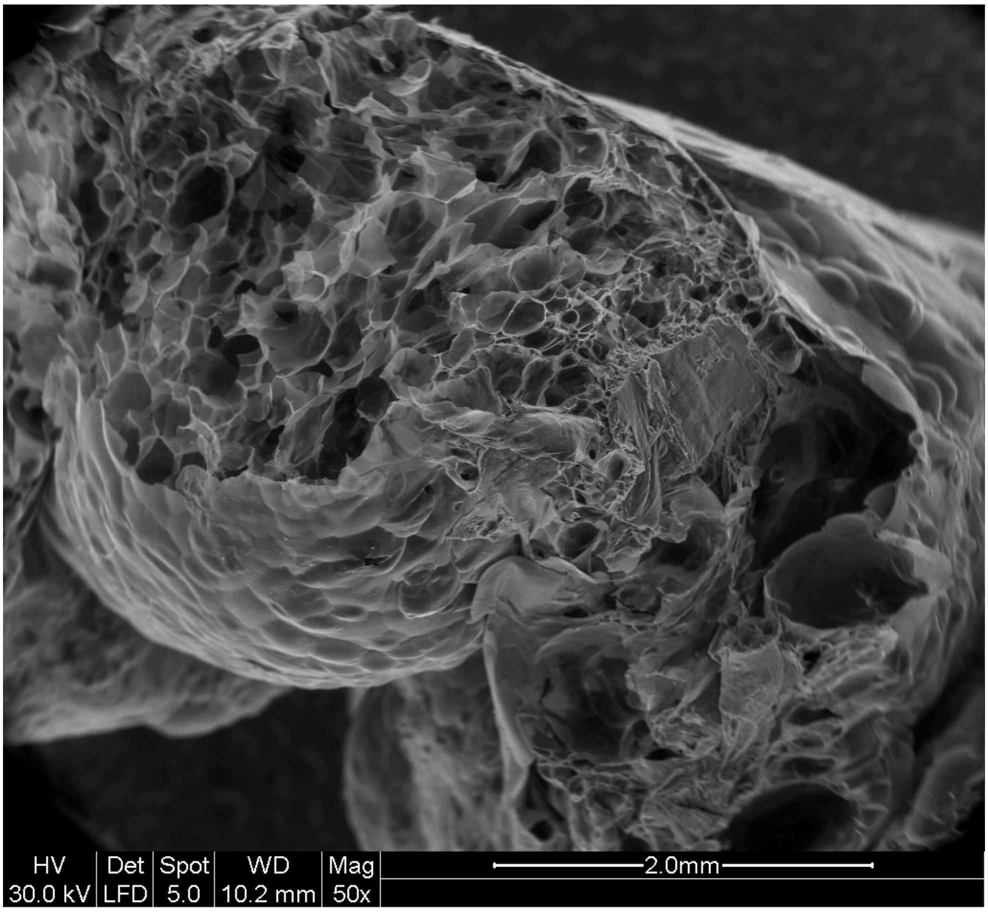


Figure 10.4 Micrograph of WR cake sample with broken surface

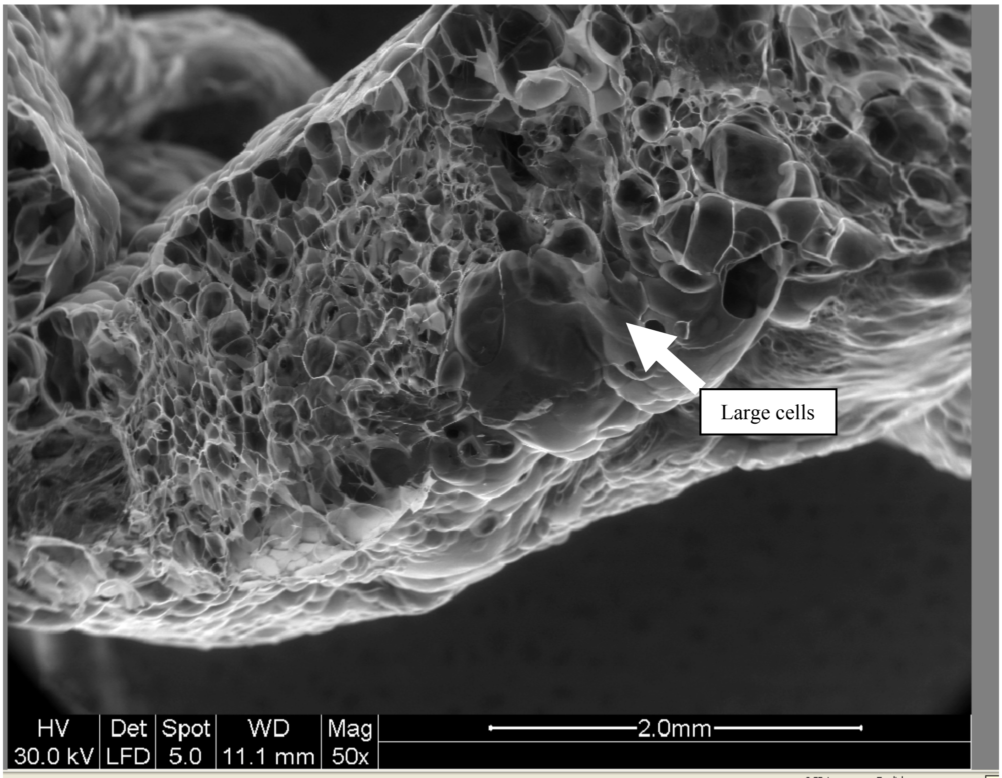
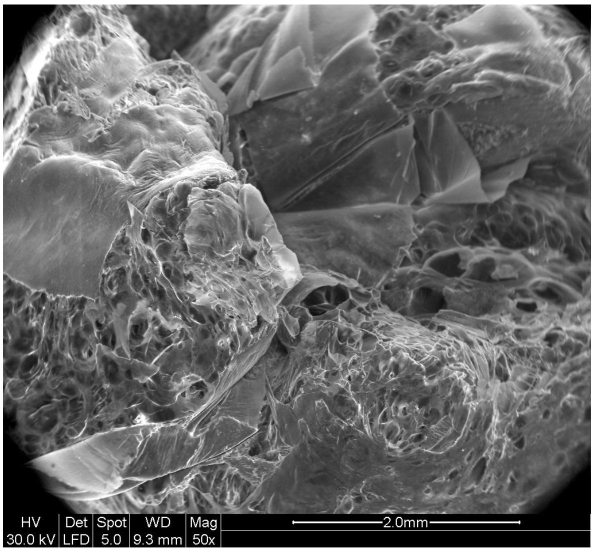


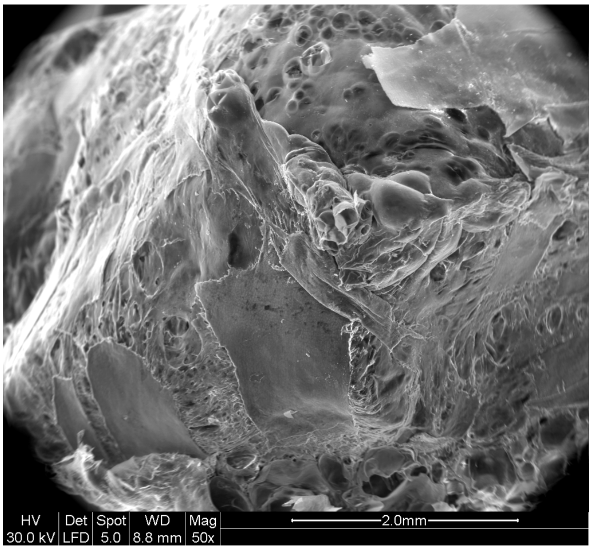
Figure 10.5 Micrograph of WR cake sample with cut surface

10.6.1 Cell distribution in rice cakes (broken surface)

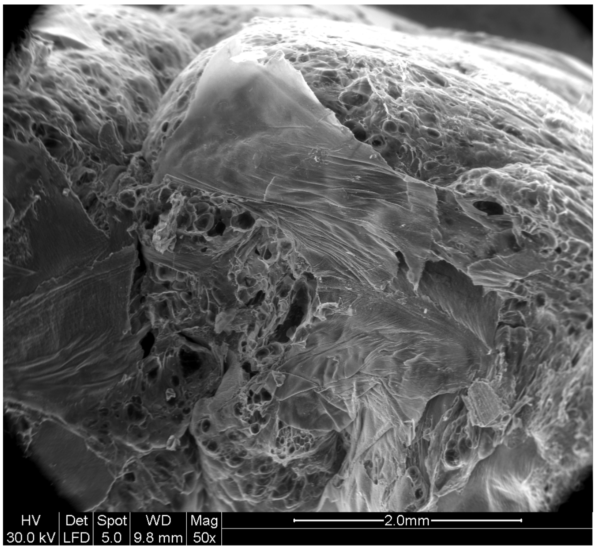
Figure 10.6 presents the cellular distributions in rice cakes samples with surfaces broken during break strength tests.



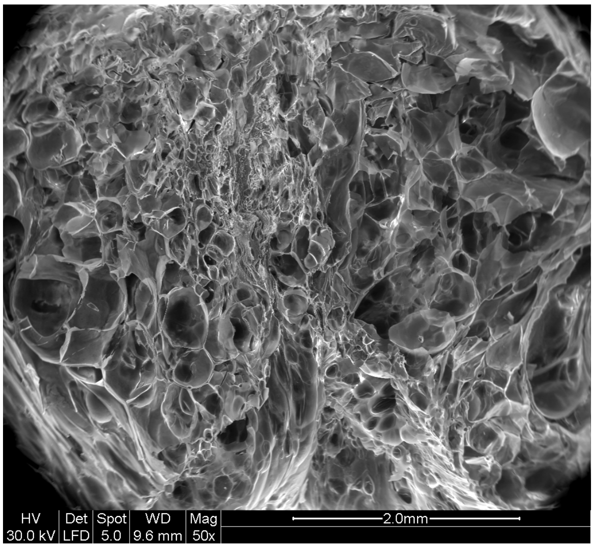
Micrograph of rice cake made from low protein rice



Micrograph of rice cake made from high protein rice



Micrograph of rice cake made from waxy rice

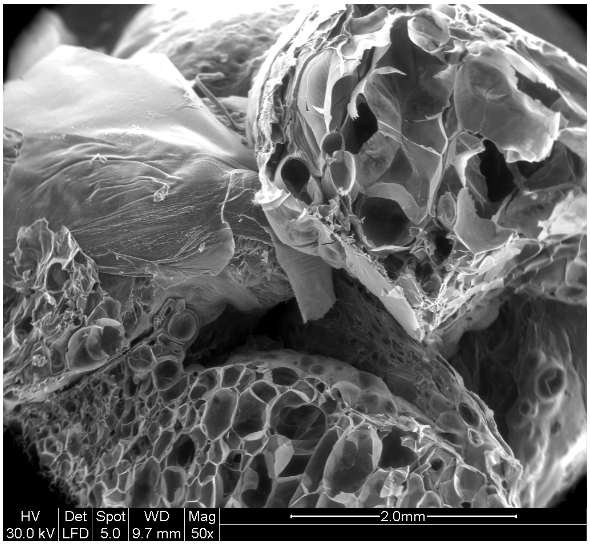


Micrograph of rice cake made from brown reference rice

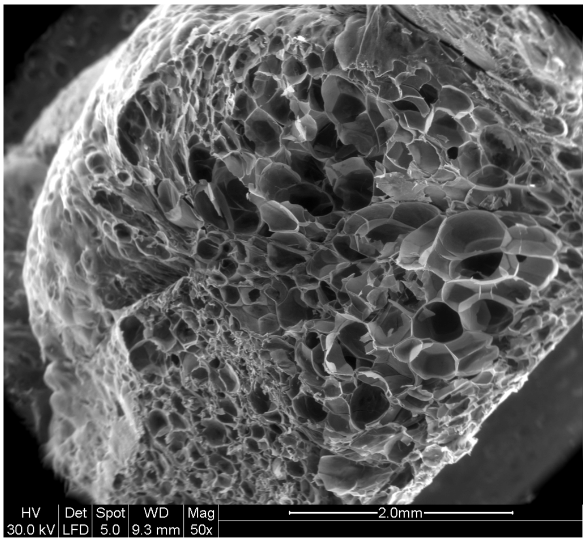
Figure 10.6 Cellular distribution of rice cakes (broken surface)

10.6.2 Cell distribution in rice cakes (cut surfaces)

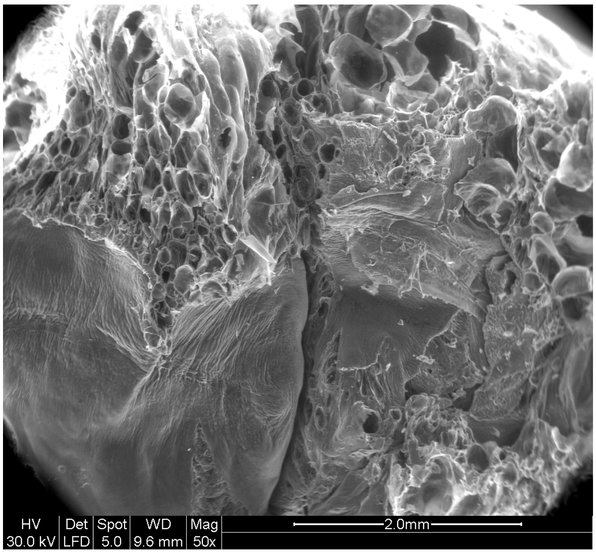
The following figure 10.7 represents the cellular distribution of rice cake cut with surgical blade and also shows that all the cakes have a heterogeneous cell size distribution.



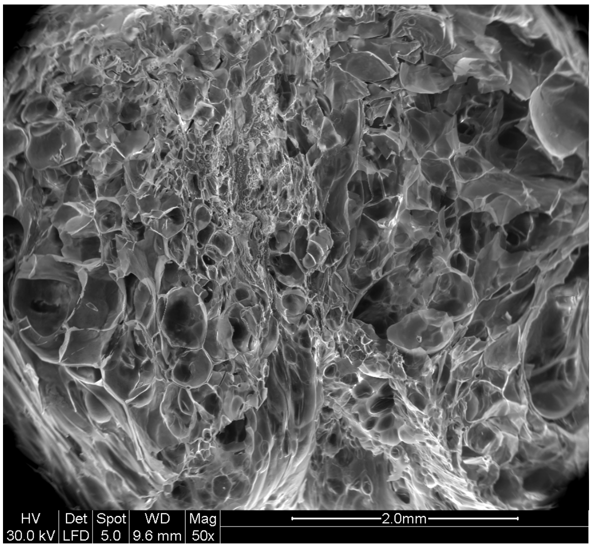
Micrograph of rice cake made from low protein rice



Micrograph of rice cake made from high protein rice



Micrograph of rice cake made from waxy rice



Micrograph of rice cake made from brown reference rice

Figure 10.7 Cellular distribution of rice cakes (cut surfaces)

The micrographs show that there is a heterogeneous distribution of the cell size, with a concentration of cells of small size on the outer boundaries of the reference sample. The surface for low protein, high protein and waxy rice show smooth layers of a thin sheet covering the interior structure of the rice cake.

These cakes show some differences to those of the reference sample. Firstly, there are few areas where the cell size can be clearly seen. This may be attributed to what has occurred during the break strength test. In the reference sample, the crack developed in a relatively straight line, from the point of application of the probe of the Instron, at the centre towards the outer edge of the cake, leaving relatively smooth fracture surfaces through the cells inside each of the structures corresponding to an original rice grain.

In contrast, for the rice cakes prepared from rice with low and high protein content as well as waxy rice, the crack has formed in a very different way. For these samples it has grown between rather than through the rice grains. As a result, the broken surface shows relatively large areas of grain surface and very few broken cells. This was confirmed by visual observation of the broken surfaces which appear like a flat plane in the reference and rough in the other samples. The kernel surfaces again show extensive smooth areas with some flaps protruding attributed to the presence of bran in the form of flakes.

In conclusion, the fracture mechanism appears to be different in the reference compared to the rice cakes made from low-protein, high-protein and waxy rice. The way in which adhesion takes place involves the gelatinisation of rice starch which comes out by cracking the surface of the individual grains of rice and hot starch matrix sticks together upon cooling. This proposed model of adhesion indicates that during a break strength test, failure has occurred when a crack has grown through the kernel in the reference cakes, and around the edges of kernels in the rice cakes made with high and low protein as well as the waxy variety. This presents strong evidence that the adhesion between individual rice kernels is superior in the control sample. The mechanism of adhesion has been consistent with the results for break strength results (Table 10.1) which indicates that the use of samples with low or high protein and low amylose have an adverse effect on the texture.

This may indicate that the difference in mechanism of failure in the stifness test is not due to puffing (which controls cell size), but is due to differences in adhesion between the kernels.

10.7 Rice compositions and rice cake characteristics

The characteristics observed for the rice samples of varying composition and the rice cakes made from them is described in Table 10.3. The total amylose content of the waxy rice is 8.2 % which is significantly lower than the reference. The protein content of waxy rice (7.3%) is also lower than that of reference sample. The standard deviation has been previously reported for volume difference as ± 3% and for break strength as ± 10%. The volume of cakes made from waxy rice is lower as compared to those for other cake samples and the cell size distribution is heterogeneous for all cake samples. The three rice varieties (low protein, high protein and waxy) used to make rice cakes have significantly lower break strengths and this is consistent with the measurements in fracture mechanism in the stiffness tests described in the preceding section of this chapter.

Table 10.3 Characteristic of rice compositions and rice cakes

Sample	**Rice characteristics**		**Rice cake characteristics**	
Rice/rice cake	Total amylose (%)	Protein content (%)	Volume (cm^3)	Stiffness (N)
Low protein	18.2	7.5	47.4	6.8
High protein	18.2	9.3	47.0	5.8
Waxy	8.3	7.3	44.7	6.5
Reference	16.0	8.2	47.1	9.0

10.8 Conclusion

There are a number of reports in the literature on the effect of amylose content on rice properties but none of these describe the effect on adhesion during manufacture of rice cakes. The amylose-amylopectin ratio determines many of the properties of rice and higher amylose content enhances the capacity of the starch granules to absorb water and expand in volume without collapsing as there is greater tendency of amylose to form hydrogen bonds with water present inside the rice grain. As the starch granules gelatinize in water to form a paste their structure and associated crystallinity is destroyed. The behavior of the resultant paste tends to be less dependent on granule structure and more dependent on molecular structure. It has been reported that the amylose content decreases during the grain development in the case of waxy rice (in the range of 1.5% - 0.3%) compared to non waxy rice (Juliano 1985). The presence of higher levels of protein increases the paste rigidity in waxy rice but decreases this for non-waxy rice. Elevated protein also has been observed to softens the texture for waxy and non-waxy rice samples in the cooked (steamed) form (Xie and co-workers 2008).

The current study shows that the puffing of the rice cakes is not dependent on the protein content. In addition the waxy rice sample had inferior adhesion compared to the reference sample. This is consistent with the literature on rice stickiness, that waxy rice is less sticky on boiling (Markar and co-workers 1991).

The evaluation of microstructure of rice cakes described here has found that cell distribution is heterogeneous for cakes prepared from the rice samples of various compositions. The cell size of rice cakes observed from either cut or broken surface were very similar. Low protein, high protein and waxy rice cakes have smooth layers of a thin sheet covering the cellular structures which make up the of rice cake.

The surface of reference rice cake was very similar regardless of whether it was prepared by being broken or cut. This indicates that the crack growth in the break strength test results in the formation of a surface which is relatively flat. Hence the crack grows through the structures corresponding to the original rice grains rather than around the grains in the adhesive layer between the grains. This means that the adhesive layer is stronger than the internal structure of the rice grain. For rice cakes having low and high protein content and waxy rice, the cracks grow in a very different way. The surface is rough rather than straight. The crack has grown between the kernels rather than through a kernel. The adhesive layer is weaker than the internal grain structure.

In conclusion, the fracture mechanism is different in the reference cake and rice cakes made from different rice composition. Adhesion is weaker in waxy or low and high protein cakes and optimum in the reference rice cakes.

Chapter 11

General discussion and conclusions

The purpose of this chapter is to briefly summarize the results obtained during the current study, draw final conclusions and make recommendations for further research into the properties and characteristics of puffed cereal products.

11.1 Introduction

A survey of the previous literature indicated that there have been very few reports on puffed rice cakes. The studies that have been conducted demonstrate the effects of various processing parameters (particularly tempering moisture, heating conditions) on the volume and colour of puffed rice cakes (Hesih and co-workers 1989, 1990). In addition, the effect of added wheat starch on robustness of brown rice cakes as well as the effect of moisture and additives on volume and texture has been evaluated (Orts and co-workers 2000). These earlier studies do not discuss what was responsible for puffing and adhesion in the rice cakes, role of mould pressure or cycle time on the texture of rice cakes and cell size distribution of the puffed products.

There have been a very limited number of scientific reports on the influence of processing variables on the manufacture of rice cakes and up until now, the primary focus has been upon the use of different types of rice, particularly comparing the application of long and short grained forms. The studies conducted up until the current investigations have been focused on the volume and colour measurements of rice cakes. Related studies were also done on manufacturing wheat cakes using rice cake equipment along with the addition of wheat starch to measure robustness in rice cakes.

The processing of cereal grains typically involves changes to the starch which gelatinizes with the heat, shear and water present inside the kernels during the puffing process. Based upon the earlier observations, changes in the formulation (by adding sugars or oil) or the processing parameters (time, temperature, tempering moisture) probably manipulates starch gelatinization thereby influencing product quality characteristics. These are likely to relate to puffing or expansion as well as crispness and texture of the finished products.

The current research has been focused on the manufacture of puffed rice cakes and the following compositional variables:

1. The use of brown compared to white rice;
2. The addition of either oil or sugar to brown rice; and
3. The use of low and high protein brown rice samples as well as waxy brown rice.

The rice cakes were manufactured in the laboratory and samples were also procured from a commercial production plant as the basis for reference and comparison. The test results described in the thesis focus on elucidating:

1. The mechanism of puffing; and
2. The mechanism of adhesion.

The results described in the earlier chapters of this thesis have been primarily divided into four broad areas:

1. Selection of processing variables for manufacture of rice cakes
2. Evaluation and analysis of rice cakes for physical properties and texture
3. Cell size distribution in rice cakes
4. Analysis of rice cakes made from other rice type for texture and cell size

In this final chapter, the results are reviewed briefly with reference to both the previous and current studies conducted.

11.2 Evaluation of effect of process variables on the physical properties of rice cakes

Rice cakes prepared using various combinations of processing conditions were analyzed for their physical properties, particularly volume and thickness. These were both found to increase with higher mould temperatures across a range of tempering moisture levels for BR, WR, and BR with added 1% oil or sugar. The results of these trials have been summarized in Chapter 7 (Table 7.8).

The relatively high temperature inside the mould accelerates moisture evaporation and gelatinization of rice starch and also increases the viscosity of the rice starch so that each cell can expand more rapidly. This increase of the diffusion rate of steam from the polymer matrix into the expanding cells increases the partial pressure and when starch gelatinizes, the branched amylopectin forms a web like network within puffed products. The network increases the product viscosity and forms a structural framework for expansion process. Therefore, higher mould temperature results in enhanced puffing.

The thickness and volume increases with increase in heating time, similar to higher mould temperature and therefore the longer heating time also gives greater puffing for BR, BR with 1% sugar or oil and WR at varying tempering moisture. A longer heating time also helps to diffuse more steam from viscous starch and results in rapid gelatinization of starch, as for higher mould temperature. The results of this study are consistent with the studies done in past.

The volume of rice cakes made from low and high protein rice varieties was also similar to the control samples at 18% moisture whereas the volume of rice cakes made with waxy rice was lower (Table 10.3). This indicates that the dominant factor for puffing is moisture level and heating (temperature and cooking time) rather than rice variety or composition. It has been suggested in the past studies that amylose content contributes positively to the expansion volume at any temperature and moisture content during extrusion of rice (Villareal and Juliano 1987). This appears to be contrary to the findings of the current studies on the waxy rice as these rice samples have very low amylose content.

The results also demonstrated that the addition of 1% oil to BR at 18% tempering level lowers the overall cake thickness and volume when the mould temperature and heating time are both increased.

11.3 Evaluation of textural properties of rice cakes at varying processing variables

The rice cakes were evaluated for break strength and texture and the results showed that these parameters were not affected substantially by changes in the mould temperature or heating time across a range of tempering moisture level. This appears to be contrary to the past literature which has suggested that an increase in the volume gives higher break properties and stiffer texture in foams.

The results for texture of rice cakes showed idiosyncratic behaviour typical of brittle foam products. The force-displacement curves were irregular and jagged and the standard deviation of measurements is high for all rice cakes. The results were consistent with the studies reported in the past.

The break strength and texture were not significantly affected by the use of brown or white rice and also there was no specific literature on the effect of bran on structural properties of rice cakes. Further the texture results suggest that rice bran and incorporation of 1% oil to brown rice can act as a barrier and reduce the overall strength of adhesion between puffed rice grains, and hence the break strength and texture as reported in Chapter 8. The lipids present in rice bran may affect the gelatinization temperature of the rice starch depending on lipid structure and ability to complex with amylose.

The break strength and textural attributes are not affected by addition of sugar but there was an overall change by the addition of oil when the processing variables were altered. It is unclear why there is no effect of sugar, as sugar is expected to affect the structural properties due to an increase in the gelatinization temperature of starch according to past studies. It has also been reported that oil affects the gelatinization temperature by forming lipid-starch complexes and are consistent with the current test results.

11.4 Effect of mould pressure and cycle time on texture of rice cakes

Cakes were prepared under varying mould pressure and the results demonstrated no significant effect on the textural attributes measured as the stiffness of the products. In the initial part of the cycle, when the mould is closed, pressure crushes the grains as well as increasing rice grain surface contact with the hot mould, causing more rapid conduction of heat. In the second part of the cycle, the mould is opened to the desired cake thickness, and puffing occurs. There is no literature which provides any indication on the effect of pressure on cake puffing, volume or break strength. Rice was tempered at atmospheric pressure and puffing occurs at approximately ambient pressure reflecting the construction of the mould which have channels to allow the steam to escape. Effectively any effect of pressure as a variable is in the initial crushing phase of rice cake manufacture.

The change in the cycle time changes the volume and break strength largely and results implies that the shorter the cycle time, the better the puffing (higher volume) and adhesion (stiffness). This concluded that adhesive bond between the rice grains is stronger at higher volumes and there was no literature on the effect of cycle time on puffing of cereal or rice cakes. It was interesting to note that the change in the volume with cycle time is much larger than with temperature and heating time.

The chosen range for cycle time (Table 7.17) produced a substantial variation in volume and considerable changes in physical properties. The chosen range for other processing variables (mould temperature, heating time or tempering levels) generated relatively small variations in volumes and no significant changes in other properties.

In summary, the processing variables (mould temperature, heating time, and moisture content) and added formulations (sugar, oil, rice type) have no significant effect on the texture (stiffness) of rice cakes. The addition of oil overall lowers the volume but even then there is no significant effect on the texture. There is no published literature on texture of rice or other cereal cakes, which is unexpected as texture is a key quality characteristic of crunchy snack foods.

11.5 Cell size distribution of rice cakes

Puffed foams tends to have a perfect order of two-dimensional honeycomb to a wide range of disordered three-dimensional networks and natural foams show a vast variation in their cell structure and texture as discussed earlier in Chapter 9. The results on the microstructures of the rice cakes presented in that same chapter demonstrate that the cells typically range in diameter between 0.25 to 0.5 mm (Figure 9.2). The main characteristic of the microstructure of the all rice cakes examined was a heterogeneous cell size distribution with areas of dense small cells and other areas of large cells. The results for the volume and cell size of all rice cakes show a linear correlation as expected i.e. the cell size increases with an increase in the volume.

All the processing variables (temperature and heating time) affect the extent by which starch changes its form, its viscosity, and also partial pressure in the cells formed during puffing. The results also showed slight trends for cell size with moisture level, temperature and heating time, as seen for volume.

11.6 Effect of BR and WR on cell size of rice cakes

The rice cakes made from BR showed the presence of flaps of bran on the surface and these are evident in micrographs presented in Chapter 9. They were also observed visually during inspection of the samples. Products made from different rice types also had a heterogeneous distribution of cell size and the ESEM micrographs in Chapter 10 showed that low protein, high protein and waxy rice surface have extensive areas of thin sheets covering the surface of the rice cakes and in some cases this may have been bran material.

The ESEM surface images of reference cake sample either cut or broken (Figures 10.2 and 10.3) were very similar in their cell distribution and this indicates that the growth of the crack during stiffness test measurement was relatively straight, similar to that found during cutting with a blade. It was observed that the crack grew through rice grains rather than around the grains, that is, in the adhesive layer between the grains. This also indicates that the adhesive layers were stronger than the internal structure of the rice grains following processing of the rice cakes.

The results for cut and broken surfaces of WR cakes were similar to that for BR cakes and for cakes made from low, high protein content and waxy rice, the cracks grew in a very different way. The surface of broken cakes is rough rather than straight (Chapter 10). The crack has grown between the grains rather than through the grains. The adhesive layer is weaker than the internal grain structure.

The heterogeneity of the cell size during the process of puffing is assumed to be due to number of the contributing factors such as the variation in the steam pressure, time and temperature variables, crushed rice grains, arrangements of the starch granules in translucent and opaque endosperms, presence of inter-granular spaces in the opaque region of the endosperms, presence of chalkiness, and the presence of the bran.

It remains unclear at this stage whether the amylose–amylopectin ratios, proteins, grain length, thickness and weight of the grains, gelatinization temperature and moisture level affect the cell size of the rice cakes. There are no reports in the literature which might provide any guidance on the contributing factors that influence the cell size of rice cakes. Hence, although the current study of cell size in rice cakes has yielded useful information, more remains to be studied if we are to fully understand the role of individual molecular components and their implications for product quality.

11.7 Major conclusions

The final conclusions of this study which are based on the mechanism of puffing and adhesion were:

1. The rice grains are heated in the hot mould and the unbound water evaporates and the rice starch melts rapidly, forming a molten paste. The higher temperature results in increased viscosity of the rice starch which expand or puff the product.

2. The temperature of the starch decreases rapidly as each cell expands due to the latent heat of vaporization until the pressure exerted by evaporation is in equilibrium with the elastic forces in the visco-elastic starch, when expansion

ceases. The dominant factor in rice cake puffing is heating temperature and time and moisture.

3. The rice grains are crushed inside the equipment before puffing and this cracks the hard bran layer so greater expansion will occur, allows more rapid diffusion of steam from the rice grains during puffing, and facilitates diffusion of starch molecules due to increased rice grain surface areas.

4. The crushed rice grains puff until they meet their neighbors and continue to puff until the mould is full. The rice grains inside the mould collide with each other and starch molecules diffuse and entangle while molten which helps in the formation of structural framework. As a result, on cooling a rigid weld is formed between rice grains and the higher the volume of grains, the higher the strength of the weld

5. There are two main factors which affect the cake strength: the mechanical strength of adhesion between the surfaces of neighbouring puffed rice grains, and the mechanical strength of individual puffed rice grains. The break strength of the cake is determined by whichever is the weaker of the two factors

6. The break strength for the rice cakes with weak adhesive layers, the cracks grow around the grains rather than through the grains and the rice cakes with strong adhesive layer the cracks grow through the grains. The break strength is not sensitive even to presence of extensive layers of bran on the grain surfaces and the dominant factor in rice cake adhesion is volume.

11.8 Possible areas for future research

This study has concentrated on the processing of rice cakes using a limited number of processing variables and a restricted number of different rice types. Some of the constraints here have included the range of different settings that can readily be achieved with existing equipment. A number of areas might be considered for future research that continues to address the ongoing issues of enhancing the quality of puffed cereal products whilst minimizing wastage and losses.

The work reported in the current thesis included a preliminary investigation of the influence of rice types upon product volume, other quality parameters particularly in relation to mechanisms of puffing and adhesion. It is strongly recommended that this be extended to:

1. A much more comprehensive investigation of the influence of composition. This should include a wider range of samples, carefully selected so that the effects of the starch, particularly amylose and amylopectin, as well as protein fractions can be studied;
2. The significance of genotype can be more thoroughly evaluated. This should encompass the use of as wide a range of genotypes as can be practically handled; and
3. The significance of milling should also be further studied so the role of bran layers and components is considered more fully.

In the context of the limited number of previous reports that have identified the potential of various non-rice based ingredients, further work on formulation could pursue these aspects by extending the range and source of such materials. This might include steps to investigate and further follow up the observations that particular proteins might contribute to adhesion and stiffness of rice cakes.

The potential of blends of grains might look at varying proportions of other cereal grains as well as some of the pseudo-cereals and starch based pulse materials. This could have advantages in terms of enhanced nutritional properties where ingredients are high in antioxidants (for example buckwheat) as well as possibly affecting the digestibility and glycemic responses if non-starch components are found to provide good adhesive and textural properties.

In conclusion, it is hoped that the work reported in this thesis will provide a strong basis for further studies of rice processing, particularly the production of appealing processed foods that provide both enjoyment along with enhanced prospects for nutritional benefits and human wellbeing. It appears that much remains to be done to ensure adequate nutrition for our expanding world population.

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